

PB-220 316

SOLID WASTE AS FUEL FOR POWER PLANTS

Horner and Shifrin, Incorporated

Prepared for:

Environmental Protection Agency
Solid Waste Management Office

1973

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SOLID WASTE AS FUEL FOR POWER PLANTS

*This final report (SW-36d) on work performed under
Federal solid waste management demonstration grant no. G06-EC-00176
to the City of St. Louis, Missouri
was written by HORNER & SHIFRIN, INC.
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A 15-page interim report of this project, *Energy Recovery from Waste*
(SW-36d.i), was published by the U.S. Environmental
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1973

1556

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA-SW-36D-73	2.	3. Recipient's Accession No. PB-220 316
4. Title and Subtitle Solid Waste as Fuel for Power Plants		5. Report Date 1973	
7. Author(s) Horner & Shifrin, Inc.		6.	
9. Performing Organization Name and Address Horner & Shifrin, Inc. Consulting Engineers 5200 Oakland Avenue St. Louis, Missouri 63110		8. Performing Organization Rept. No.	
12. Sponsoring Organization Name and Address U.S. Environmental Protection Agency Office of Solid Waste Management Programs Washington, D.C. 20460		10. Project/Task/Work Unit No.	
		11. ~~XXXXXX~~ /Grant No. G06-EC-00176	
		13. Type of Report & Period Covered Final	
15. Supplementary Notes		14.	
16. Abstracts This report summarizes a study that determined the technical and economic feasibility of burning municipal solid waste as supplementary fuel in large suspension-fired utility boilers. Adaptation of commercially available solid waste materials handling and processing equipment was studied. Even though the study is referenced to the St. Louis, Missouri, metropolitan area, study results should be applicable to other heavily developed metropolitan areas of the U.S. As a result of this study, the U.S. Environmental Protection Agency is supporting a full-scale demonstration of the concept in St. Louis. A brief description of the demonstration project is presented in a 1972 EPA report <i>Energy Recovery from Waste</i> . The report is available from the U.S. Government Printing Office, Washington, D.C. 20462, for 25¢.			
17. Key Words and Document Analysis. 17a. Descriptors *Refuse disposal, *Garbage disposal, Grinders, Magnetic separators, Pneumatic conveyors, Fly ash, Air pollution control equipment, Water tube boilers			
17b. Identifiers/Open-Ended Terms *Storage--waste disposal, Energy conversion, St. Louis (Missouri)			
17c. COSATI Field/Group 13B			
18. Availability Statement Release to public		19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 158
		20. Security Class (This Page) UNCLASSIFIED	22. Price

This report has been reviewed by the U.S. Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of commercial products constitute endorsement or recommendation for use by the U.S. Government.

An environmental protection publication (SW-36d) in the solid waste management series.

SUMMARY

The study summarized in this report was directed toward the determination of the technical and economic feasibility of burning prepared municipal refuse as supplementary fuel in large suspension-fired utility boilers. The study was conceived under the premise that if municipal refuse were properly prepared, and if the percentage of refuse to pulverized coal were kept to a practical minimum, potential operating problems in large boiler installations would be little, if any, different than if only coal were fired.

The study included consideration of the physical and chemical characteristics of raw refuse, and of refuse with certain of its components removed. Consideration also was given to the characteristics of the ash and residue resulting from the combustion of refuse, and to the potential effects upon operation and maintenance of the components of boiler units.

Adaptation of commercially available mechanical equipment for the processing and handling of raw and prepared refuse was studied. The studies included consideration of the modifications required for application of the process for those types of boilers in common use.

An assessment was made of the capability of major utility boiler installations to consume sufficient refuse as supplementary fuel to serve as a significant method of refuse disposal for metropolitan areas. The relative economics of the full-scale application of the process also was assessed.

An evaluation was made of the effects of the process upon public health and air pollution control. Consideration was given to the social and economic relationships between utilities and public agencies having bearing upon the application of the process.

For convenience of assessment of specific details of equipment and circumstances, the study is referenced to the St. Louis, Missouri metropolitan area. It is considered that this area may be regarded as being reasonably typical of the metropolitan areas of the most heavily developed portions of the United States.

Consideration was given to the type and the scale of facilities required to effectively test the processing, transporting, and firing of refuse to a boiler, and to properly evaluate the effects of firing refuse as a supplementary fuel upon the operation of a boiler.

CONCLUSIONS

The principal conclusions resulting from the study summarized herein are as follows:

1. The process is physically and technically feasible, under the premises that refuse would be milled to effect a particle size of about one inch, and that the milled refuse would replace approximately 10 per cent of the heat value of the pulverized coal consumed in suspension-fired boiler furnaces.
2. Potential operating problems accruing from firing milled refuse as supplementary fuel to large boiler furnaces probably are minimal. Actual adverse effects, if any, can be assessed completely only by full-scale testing of a typical boiler unit over a reasonable period of time.
3. The process can be applied by adaptation of existing technology and commercially available mechanical equipment, with the probability that essentially no further developmental effort would be required. Modifications to existing suspension-fired boilers normally would be minor.
4. Considering that the milled refuse has a value as fuel to large utility boilers on the order of \$2.50 to \$4.00 per ton, the net cost of the disposal of refuse by the process should be highly attractive in many of the metropolitan areas of the United States.
5. The capability of suspension-fired boilers to consume the prepared refuse as supplementary fuel is great enough to permit the process to serve as a principal method of refuse disposal for many metropolitan areas, even when the supplementary fuel is fired as only 10 per cent of the total fuel. By 1973, the suspension-fired boilers in the St. Louis area will have the potential capability of consuming over twice the amount of refuse produced in the entire metropolitan area.
6. Ambient air quality in many metropolitan areas could be improved by application of the process.

RECOMMENDATIONS

Although the probabilities of adverse effects upon the components of large utility boilers by application of the process appear to be minimal, one area of uncertainty relates to the long-range effects upon boiler operation, such as in corrosion and bottom-ash handling. The Union Electric Company of St. Louis, Missouri, which has cooperated fully in this study, has indicated it would consider a specific proposal for the use of one of its major boiler units as a prototype. Since the testing of a large boiler unit on less than a full-scale basis is not considered to be sufficient to adequately assess the effects of the process, the following recommendations are made:

1. Arrange for the purchase and installation of equipment to process refuse, to transport the processed material to the boiler unit designated by the Union Electric Company, and to fire the material as supplementary fuel to the boiler unit for a period of approximately two years. The most desirable installation for this purpose would be one which would permit full assessment of processing operations as well as boiler performance. Since the process has the promise and potential of being significant as a primary means of refuse disposal for a large part of the United States, it is believed appropriate that the financing of a prototype installation be underwritten by the Federal Government.
2. The most critical areas of investigation are believed to relate to boiler operation and performance. Should the financing of full-scale processing operations not be practical at this time, it is recommended that facilities be installed to permit full-scale testing of the boiler, even should it be necessary to forego the complete installation and testing of the refuse processing equipment.

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PART I

PREFACE

BACKGROUND

All major metropolitan areas within the United States face an increasing problem in the disposal of solid waste materials. For the most part, the technology utilized to date in the current methods of solid waste disposal has not been sufficiently sophisticated to permit efficient conservation of natural resources. Further, it appears likely that full advantage has not been taken of proven areas of technology in the disposal of refuse.

The recovery of waste heat resulting from the incineration of municipal refuse is the exception, rather than the rule, in existing municipal incinerator installations within the United States. In those plants in which waste heat is recovered, the only fuel usually is raw municipal refuse, which is charged to the furnaces essentially in the form it is delivered to the plants, without any attempt to control particle size or other characteristics. Certain of the existing incineration facilities have provisions for the firing of oil or gas, which is used when either the quantity or the composition of the refuse is not adequate to maintain the required furnace temperatures. There are a number of refuse incineration plants in Europe equipped with waste heat boilers which use auxiliary fuel.

Available operating data from both United States and European refuse incinerators with waste heat boilers are incomplete and inconsistent. It is generally held, however, that such plants in the United States often are troubled with excessive slagging, corrosion, and boiler tube deposits. Limited information regarding European plants indicate that the same problems exist in their facilities, but the published reports from Europe appear to place less emphasis upon these problems.

Incinerators burning only municipal refuse are relatively inefficient, due to the necessity of maintaining furnace temperatures less than 2,000 degrees F. in order to prevent excessive slagging. Substantial quantities of excess air are required to control refuse incinerator furnace temperatures. Coal-fired boilers, however, are far more efficient, operating at higher furnace temperatures and with relatively low percentages of excess air. It follows that if means were found to burn refuse under the conditions prevailing in coal-fired boilers, without creating additional operating problems, more efficient combustion of refuse could be achieved.

This study was conceived under the premise that if municipal refuse were properly prepared before firing, and if the percentage of refuse to coal were kept to a practical minimum, operational problems in large boiler installations fired with both refuse and coal as fuel would be little, if any, different than when the fuel is entirely coal. Further, presuming no

significant adverse effects upon coal-fired boilers and their auxiliary equipment from such a combination of fuels, it would be possible to implement the process by adaptation of existing technology and mechanical equipment, with the probability that little further developmental effort would be required. The premise is supported by many industrial installations, which recover heat for the production of steam and power from the combustion of waste materials, such as wood bark and bagasse, which have fuel characteristics comparable to those of prepared refuse. One industry, the Eastman Kodak Company, has let a contract for the construction of a suspension-fired boiler to burn shredded solid waste materials from their own operations.

The order of magnitude of potential savings also was considered when this study originally was conceived. The overall economics of burning refuse as supplementary fuel may be determined by subtracting the value of the refuse as fuel from the cost of preparing and firing the material to boilers, and comparing this difference with the applicable and comparable costs of refuse disposal by other means. Depending upon the geographical location of a specific case, which often controls the value of fuel as well as the costs of refuse disposal, indications are that the overall economic advantage of the use of prepared refuse as supplementary fuel could be as high as \$6.00 to \$8.00 per ton in certain of the heavily populated areas in the northeast part of the United States.

For convenience of reference, and to permit evaluation of specific conditions and facilities, this study is based partially upon the circumstances prevailing in the St. Louis Missouri metropolitan area. It should be borne in mind that the conditions and facilities of the St. Louis area relating to refuse disposal and to the generation of power from boilers burning coal in suspension apply relatively equally to most of the larger metropolitan areas of the United States, particularly those in the northern and eastern portions of the country.

Within the St. Louis metropolitan area, the total population is on the order of 2,500,000. The solid refuse produced in the area approximates a total of 4,000 tons per day. The major electric utility in the area is the Union Electric Company, which operates a number of coal-burning power generating stations within a relatively few miles of the center of the metropolitan area. The total amount of coal consumed by these stations in 1968 was an average approximating 17,000 tons per day. The production of electric energy is increasing in the St. Louis area at the rate of about 7 per cent per year, a much greater rate of increase than that of population. Since refuse production is roughly proportional to population, it appears that the ratio of coal consumption to the production of refuse, presuming the continued use of coal as fuel, will increase even further.

STUDY OBJECTIVES

The primary objective of the study summarized in this report is to determine the feasibility of firing controlled small percentages of prepared

municipal refuse with coal for use as fuel in large utility boiler plants. Subsidiary objectives of the study include:

1. Determination of the physical feasibility of the proposed process.
2. Determination of the relative economic aspects of the proposed process.
3. Evaluation of potential long-range problems resulting from the proposed process.
4. Evaluation of the potential impact of the proposed process upon the overall refuse disposal problem.
5. Evaluation of the effects upon public health and air pollution control by the proposed process.
6. Evaluation of the required management relationships between a municipal corporation and a public utility in the full scale application of the proposed process.

For the proposed process to be effective to a public utility as a possible means of economizing on the costs of fuel, and to a municipal corporation as a significant means of disposing of solid wastes, it must be conducted on a reasonably large scale. This study therefore is confined to the consideration of larger utility boilers, in which even a small percentage of prepared refuse in the fuel would be a sizable portion of the solid wastes generated in a given metropolitan area.

PART II

REFUSE CHARACTERISTICS

GENERAL

Consideration of the use of refuse as fuel requires that its composition and quality be examined as thoroughly as the available data permit. The predominant characteristic of raw refuse is its apparent lack of homogeneity. However, analyses of refuse produced in different parts of the United States, within reasonable limits, have been found to be surprisingly similar. The principal variation in quality in this country apparently is due to differences in climate. For example, refuse produced in the southern States normally contains a far greater percentage of vegetable matter, with a correspondingly greater percentage of moisture, than that produced in the central and northern parts of the country, because of the differences in growing seasons.

The greatest potential variation in refuse composition in the St. Louis area is considered to be in industrial refuse. Such refuse normally is collected separately from domestic wastes, and with proper precautions, can easily be kept apart from wastes contributed from domestic sources. For purposes of this study, the quality of refuse contemplated as potential fuel for utility boilers will be considered to be that of mixed municipal refuse as collected by City of St. Louis vehicles, consisting of only the solid wastes collected from households and from small commercial establishments. Imposition of this limitation should have the effect of reducing the possibility of large quantities of unacceptable material being fired to a boiler. It should be borne in mind, however, that certain selected industrial and commercial wastes may have substantially higher fuel values than domestic refuse.

QUANTITY OF REFUSE

The largest fleet of refuse collection vehicles within the St. Louis metropolitan area is that operated by the City of St. Louis. All refuse collected by this fleet presently is disposed of at two municipally operated refuse incinerators, one located in the southeast part of the City and the other in the northeast part. These vehicles collect mixed refuse only from households and small commercial establishments. The monthly quantities of mixed refuse collected by City of St. Louis vehicles for the period from April 1962 through March 1968 are summarized in Table No. 1. Assuming an economic pattern favorable to the City, all of the refuse collected by the City of St. Louis fleet would be available for processing and subsequent firing to utility boilers. The City collection vehicles normally make their

TABLE NO. 1

DOMESTIC MIXED REFUSE
COLLECTED BY MUNICIPAL TRUCKS
CITY OF ST. LOUIS, MISSOURI
(TONS)

	1962/1963	1963/1964	1964/1965	1965/1966	1966/1967	1967/1968	Average
Apr.	18,649	18,959	19,652	19,785	18,332	17,611	18,831
May	20,081	19,792	17,764	17,357	19,693	20,248	19,156
Jun.	19,291	17,642	18,479	20,140	19,243	21,442	19,373
Jul.	20,295	20,316	19,653	20,145	17,962	21,104	19,912
Aug.	19,821	19,390	17,914	19,542	21,969	19,447	19,681
Sep.	16,564	17,394	18,026	19,275	19,322	18,399	18,163
Oct.	18,833	18,215	17,060	16,596	17,664	18,427	17,799
Nov.	17,271	16,704	16,460	18,003	17,711	17,618	17,294
Dec.	15,884	16,231	16,986	18,213	16,498	16,258	16,678
Jan.	16,878	16,670	14,787	14,956	16,237	17,053	16,097
Feb.	14,213	14,095	13,829	13,808	13,917	14,913	14,129
Mar.	17,559	17,568	17,194	18,153	19,625	17,209	17,885
Totals	215,339	212,976	207,804	215,971	218,173	219,729	214,998
Average	17,945	17,748	17,317	17,998	18,181	18,311	17,916

collections twice per week, on a five-day basis. Saturday collections are made only when the trucks are not able to complete their collections during the normal five-day week.

Most of the domestic refuse produced in the remainder of the St. Louis metropolitan area is collected by private haulers. From City of St. Louis data, the average per capita collection of domestic refuse is equivalent to about 2.0 pounds per day. With a total metropolitan area population of about 2,500,000, the total daily production of domestic refuse only would be about 2,500 tons. Studies made in 1963-1964 for St. Louis County, Missouri ("Solid Waste Disposal Study for St. Louis County, Missouri," Horner & Shifrin, Inc., 1964) with a population then totaling about 778,000, indicated the average per capita refuse collection from all sources to be about 3.10 pounds per day. Using this value, the estimated total daily refuse production for the entire metropolitan area would be on the order of 4,000 tons.

REFUSE COMPOSITION AND QUALITY

The composition, as well as the physical and chemical characteristics of as-received municipal refuse can be expected to vary substantially. Significant seasonal variations occur in addition to those occurring daily and even hourly in each truckload of refuse delivered to a disposal site. The variations in the sizes of the components and the lack of homogeneity of raw refuse create difficulties in sampling and analysis, and because of the time and expense required for such investigations, there consequently are few reliable data available regarding physical characteristics and chemical composition.

It should be understood that the data presented in the following paragraphs relate to raw refuse and to the residue and slag resulting from the incineration of raw refuse in conventional incinerators. As a consequence, the data are presented herein only for purposes of guidance and general information.

Among the most recent and reliable data on refuse composition and quality are those derived from tests made on Long Island refuse by Kaiser, et al (1), at the Oceanside Refuse Disposal Plant, Nassau County, New York, in 1966 and 1967, and from tests made by Purdom, et al (2), at Philadelphia, Pennsylvania. Table No. 2 summarizes the composition ranges determined by these tests of as-received refuse as per cent by weight. The similarities between the two sets of analytical results are apparent. It is believed that the refuse produced within the metropolitan St. Louis area would have a comparable range of composition.

The average proximate and ultimate analyses, together with the calorific value of the Long Island refuse, were determined by Kaiser to be as indicated in Table No. 3. Again, these analyses are believed to be comparable to those which would be obtained from average St. Louis refuse.

TABLE NO. 2

COMPOSITION RANGES OF REFUSE
WEIGHT PER CENT, AS RECEIVED

	<u>Oceanside</u> (4 lots)	<u>Philadelphia</u>
Paper	33.72 - 53.33	54.4
Textiles (Rags)	2.24 - 3.97	2.6
Rubber, Plastics, Leather	2.45 - 8.82	1.7
Garbage	7.23 - 16.70	5.0
Wood	1.22 - 6.58	2.4
Glass and Ceramics	7.13 - 11.87	9.1
Metal	7.23 - 10.60	8.4
Ash and Dirt	-----	16.4
Grass, Leaves and Dirt	0.26 - 33.33	----

TABLE NO. 3

AVERAGE ANALYSIS AND CALORIFIC VALUE OF REFUSE

<u>Proximate Analysis</u>	<u>Weight %</u>
Moisture	28.0
Volatile Matter	43.4
Fixed Carbon	6.6
Glass, Ash, Metal	<u>22.0</u>
	100.0

<u>Ultimate Analysis</u>	<u>Weight %</u>
Moisture	28.0
Carbon	25.0
Hydrogen	3.3
Oxygen	21.1
Nitrogen	0.5
Sulfur	0.1
Glass, Ceramics, Stones	9.3
Metals	7.2
Ash, Other Inerts	<u>5.5</u>
	100.0

<u>Heating Value</u>	<u>Btu per Lb</u>
Organic	4,400
Partial Oxidation of Metal	<u>100</u>
	4,500

The compositions and moisture contents of the components of refuse samples taken at four different times by Kaiser on Long Island are summarized in Table No. 4. The ultimate analyses of these refuse components, together with the high heat values of the components, are indicated in Table No. 5. The results of the tests indicate that the calorific values of the refuse components vary inversely with the moisture plus the inert material. The variation in moisture content of the combined refuse, as shown in Table No. 4, was experienced when no rain had fallen. The amount of additional moisture to be expected in refuse during a rainy period is not known.

As shown in Table No. 4, the tests made of refuse sampled on June 1, 1966, showed an average weighted moisture content of 42.1 per cent. Grass, dirt and leaves comprised one-third of this sample, and this component alone was found to have a moisture content of 62.2 per cent. It will be noted that most of those other refuse fractions capable of absorbing moisture in this sample also indicate higher moisture contents than are shown in the other tests. Since no rain had fallen, this may indicate the absorption of some of the moisture from the grass, dirt and leaves. The refuse sampled on June 1, 1966, a Wednesday, might well have included yard cuttings from the previous weekend. By comparison, the sample taken on June 23, 1966, a Thursday, did not contain nearly as great a percentage of yard cuttings or of moisture.

The total possible variation in the percentage of noncombustibles and metals in refuse is not known, and may vary widely in the refuse produced in different parts of a given community. The probable variation is estimated to be between 20 and 35 per cent of the total refuse.

The proportion of waste paper products in the samples ranged between 33 and 53 per cent of the refuse. The garbage (food wastes) fraction ranged from 7.2 to 16.7 per cent, two-thirds of which was moisture. The ASTM volatile matter test, as indicated in Table No. 3, shows the fraction of the refuse that is distilled off by rapid heating in the absence of air. Over 85 per cent of the moisture and ash-free organic matter is thus evolved as gas and vapor, about twice as much as from bituminous coal. It may be concluded that most of the combustion of refuse in a conventional incinerator furnace takes place in the gas space rather than at the surface of the refuse.

According to Kaiser (1), the calculation of the calorific value of refuse components from chemical analysis, similar to the Dulong formula for coal and coke, has not yet been solved satisfactorily. The wide variety of materials in refuse, the effect of refuse nitrogen, and carbonates in the minerals in sized papers, all apparently tend to increase the potential errors.

CHARACTERISTICS OF ASH AND RESIDUE FROM REFUSE

As in the case of raw refuse, the composition, as well as the physical and chemical characteristics of refuse ash and residue, is variable. There

TABLE NO. 4

REFUSE COMPOSITION AND MOISTURE CONTENTS
(OCEANSIDE)

Category	Test 1 (Wednesday) June 1, 1966		Test 2 (Thursday) June 23, 1966		Test 3 (Tuesday) Feb. 21, 1967		Test 4 (Wednesday) April 5, 1967	
	Weights, Per Cent	Moisture, Per Cent	Weights, Per Cent	Moisture Per Cent	Weights, Per Cent	Moisture Per Cent	Weights, Per Cent	Moisture Per Cent
Cardboard	1.59	23.78	6.75	13.22	5.78	16.10	6.81	14.27
Newspaper	8.88	37.77	11.27	19.20	21.35	18.00	12.75	19.05
Misc. Paper	22.25	36.93	21.78	24.68	26.20	21.90	24.70	21.88
Plastic Film	1.76	18.80	1.77	20.47	1.20	2.85	1.09	12.43
Other Plastics, etc.	0.69	20.50	1.67	29.60	2.34	4.38	7.73	6.26
Garbage	9.58	65.25	10.21	73.45	16.70	59.80	7.23	55.75
Grass, Dirt, Leaves	33.33	62.20	19.00	44.80	0.26	21.08	17.89	23.69
Textiles	3.00	31.40	3.33	22.40	2.24	26.05	3.97	15.30
Wood	1.22	24.98	6.58	8.70	1.46	13.20	3.47	14.80
Mineral (Glass, etc.)	9.74	6.00	9.49	1.99	11.87	1.64	7.13	2.23
Metallic	7.96	10.83	8.15	2.76	10.60	4.46	7.23	8.35
	100.00		100.00		100.00		100.00	
Avg. Moisture, % Weighted		42.10		27.06		21.18		19.57

TABLE NO. 5

ULTIMATE ANALYSES OF REFUSE COMPONENTS
WEIGHT PER CENT
BTU(HHV) PER POUND, DRY BASIS

<u>Category</u>	<u>Carbon</u>	<u>Hydrogen</u>	<u>Oxygen</u>	<u>Nitrogen</u>	<u>Sulfur</u>	<u>Inerts*</u>	<u>Btu/lb</u>
Cardboard	45.52	6.08	44.53	0.16	0.14	3.57	7,841
Newspaper	48.36	6.13	42.30	0.14	0.11	2.96	8,266
Misc. Paper	44.00	6.15	41.65	0.43	0.12	7.65	7,793
Plastic Film	67.21	9.72	15.82	0.46	0.07	6.72	13,846
Other Plastics, etc.	47.70	6.04	24.06	1.93	0.55	19.72	9,049
Garbage	41.72	5.75	27.62	2.79	0.25	21.87	7,246
Grass and Dirt	36.20	4.75	26.61	2.10	0.26	30.08	6,284
Textiles	46.19	6.41	41.85	2.18	0.20	3.17	8,036
Wood	48.30	5.97	42.44	0.29	0.11	2.89	8,236
Mineral**	0.52	0.07	0.36	0.03	0.00	99.02	84
Metallic**	4.54	0.63	4.28	0.05	0.01	90.49	742

* Inerts are ash except in Metallics, when inerts are almost entirely metals.

** Btu in labels, coatings, and remains of contents of containers.

are few reliable data available relating to these characteristics. Again, the heterogeneous nature of the material, with corresponding variations in composition, together with the time and expense required in sampling and analyzing incinerator ash and residue, have had the effect of discouraging research and investigation along this line.

Among the most recent and comprehensive data available are those derived from the tests made by Kaiser, et al (1), at the Oceanside Refuse Disposal Plant in Nassau County, New York. Table No. 6 summarizes the results of the residue analyses made at Oceanside.

The non-combustible fraction of the residue was found to be 34.7 per cent of the apparent weight of the refuse fired. While this percentage is higher than indicated by the raw refuse analysis, it is within the range to be expected during a relatively short sampling period.

Similar analyses were made by Kaiser, et al. on residue from a refuse incinerator at Stamford, Connecticut. The results of these analyses are presented in Table No. 7.

Other studies were made by the Bureau of Mines, U.S. Department of the Interior (3), of refuse incinerator residue from five plants in the Washington, D.C. area in 1966. The results of these tests are summarized in Table No. 8. Considering the heterogeneous characteristics of the residues and the difficulties of sampling and analysis, the results of the six tests presented are surprisingly consistent, especially the major fractions. The smaller fractions show greater variation, which is to be expected because of the relatively small amounts present in the samples.

A comparison of residue composition from the Oceanside Refuse Disposal Plant, the Stamford, Connecticut, incinerator and the five plants from the Washington, D.C. area are presented in Table No. 9. Certain of the differences indicated in Table No. 9 may be explained by process differences. For example, the clinkers produced at Oceanside contained fused ash, glass, ceramics and metal, which accounts for the lower glass and metal content of the remaining residue. The fly ash collected at Oceanside was added to the grate residue and siftings, probably increasing the residue by 6 to 7 per cent.

CHARACTERISTICS OF SLAGS RESULTING FROM THE INCINERATION OF REFUSE

Conventional incinerators burning refuse only often experience the formation of clinkers in the refuse fire and the formation of sintered and fused deposits on the interior faces of furnace enclosures. In an effort to determine the sources of the clinkers and deposits, tests were made by Kaiser, et al (1), on samples of refuse components to determine ash constituents and ash fusion temperatures. The results of these tests are summarized in Table No. 10.

TABLE NO. 6

CLASSIFICATION OF TOTAL RESIDUE

	Pounds, Dry	Per Cent	Ignition Loss	
			Per Cent	Pounds
Ferrous Metal	943.97	15.75	0	0
Tin Cans, etc.	828.25	13.82		
Other	115.72	1.93		
Magnetic Flakes	227.32	3.80	0	0
Non-Ferrous Metal	18.04	0.30	0	0
Glass Over 1/4-Inch	567.72	9.48	0	0
Ceramics, Stones	90.53	1.51	0	0
Clinker, Over 3-Inch	487.76	8.15	0	0
1/4 x 3-Inch	956.50	15.96	0	0
Ash, Non-Magnetic:				
1/4 x 10 M	373.23	6.23)		
Minus 10 M	590.79	9.87)	10.67	102.86
Combustible:				
Paper, Wood, Char	107.43	1.79	84.04	90.29
Putrescible (Visual)	4.11	0.07	55.63	2.29
Bones, Pits	1.82	0.03	43.38	0.79
In Conveyor Water	1,620.90	27.06	34.42	558.3
Total	5,990.12	100.0		754.53
Less Salt	-26.5			
Net Residue	5,963.6 Lb.			
Combustible-Free Residue	5,209.1 Lb.			

TABLE NO. 7

CLASSIFICATION OF STAMFORD INCINERATOR RESIDUE,
DRY BASIS, WEIGHT PER CENT

	<u>Per Cent</u>
Metal, Ferrous over 1/4-Inch	13.75
Magnetic Fe Oxide over 1/4-Inch	3.03
Magnetic Fe Oxide under 1/4-Inch	5.97
Non-Ferrous Metal over 1/4-Inch	0.83
Glass over 1/4-Inch	36.63
Ceramics over 1/4-Inch	4.73
Clinkers over 3-Inch	6.75
Clinkers 1/4 x 3-Inch	10.48
Non-Magnetic under 1/4-Inch:	16.00
Organic 1.92%	
Inert 14.08%	
Combustible over 1/4-Inch:	1.83
Paper 0.59*	
Putrescible (Visual) 1.24*	
Total	100.00

*Ash Content not Determined.

TABLE NO. 8

COMPOSITION OF INCINERATOR RESIDUES
WASHINGTON, D.C. AREA

Sample	A-1	B	C	A-2	D	E	Average
Date Obtained	7-27-66	10-15-66	10-4-66	11-10-66	11-30-66	12-20-66	---
Wet Weight, Lb	634.0	771.3	836.3	1,127.0	1,210.0	1,108.3	951.2
Dry Weight, Lb	408.3	539.3	563.5	678.3	772.5	838.3	636.3
Wet Bulk Density, Lb/Yd ³	(a)	820.8	920.7	1,050.3	1,028.7	896.4	943.3
Dry Bulk Density, Lb/Yd ³	(a)	521.1	577.8	591.3	548.1	634.5	574.5
Moisture, Per Cent	35.6	30.2	34.2	39.8	36.2	24.4	33.4
Tin Cans, Per Cent (b)	16.3	17.2	17.3	17.3	16.3	18.6	17.2
Mill Scale and Small Iron, Per Cent (b)	5.5	5.0	8.0	7.2	6.6	8.4	6.8
Iron Wire, Per Cent (b)	1.3	0.6	0.6	0.3	0.4	1.0	0.7
Massive Iron, Per Cent (b)	3.4	1.2	4.0	4.7	2.2	5.7	3.5
Non-Ferrous Metals, Per Cent (b)	3.7	1.0	0.7	1.1	0.6	1.2	1.4
Stones and Bricks, Per Cent (b)	1.1	1.5	1.9	1.5	0.8	0.8	1.3
Ceramics, Per Cent (b)	(a)	1.0	0.6	0.6	0.6	1.5	0.9
Unburned Paper and Charcoal, Per Cent (b)	3.9	9.6	12.3	9.2	8.5	6.3	8.3
Partially Burned Organics, Per Cent (b)	0.1	1.3	0.6	0.8	0.9	0.6	0.7
Ash, Per Cent (b)	14.5	15.0	16.3	16.7	17.6	12.1	15.4
Glass, Per Cent (b)	50.2	46.6	37.7	40.6	45.5	43.8	44.1

(a) Not Determined.

(b) Dry Weight Basis.

TABLE NO. 10

ASH ANALYSES AND FUSION TEMPERATURES OF MUNICIPAL REFUSE COMPONENTS

ASTM Fusion Temp., F.		Clear Glass	Brown Glass	Green Glass	Garbage Less Bones	Card- board Corrug.	* Misc. Paper	Grass and Dirt	Textiles etc.	Heavy Plastics, Leather, and Clam Shells
Initial	TID	1,480	1,620	1,640	2,020	2,060	2,160	2,080	2,040	2,100
Softening	H=W	1,600	1,700	1,720	2,100	2,120	2,260	2,200	2,120	2,160
Softening	H=W/2	1,680	1,740	1,800	2,140	2,160	2,300	2,240	2,180	2,220
Fluid	Fluid	1,840	2,080	2,080	2,200	2,240	2,480	2,320	2,240	2,300
Analyses, %										
Silica	SiO ₂	74.11	71.86	75.21	46.35	47.92	48.27	61.50	38.85	34.18
Alumina	Al ₂ O ₃	4.97	7.21	9.42	4.29	6.97	7.02	6.98	5.71	6.22
Calcica	CaO	9.36	11.70	8.62	20.70	18.08	11.70	12.87	23.65	31.04
Ferric Oxide	Fe ₂ O ₃	0.09	0.04	0.03	2.86	4.28	3.21	1.69	3.14	2.09
Titanica	TiO ₂	Tr.	Tr.	Tr.	1.04	7.21	8.69	1.83	8.62	9.23
Magnesia	MgO	8.16	0.43	0.02	11.06	9.62	8.94	7.61	9.34	8.71
Barium Oxide	BaO	0.07	0.08	0.11	0.02	0.41	0.03	0.37	0.07	0.04
Soda	Na ₂ O	2.09	6.02	4.31	5.01	3.26	5.72	2.09	3.84	4.19
Potash	K ₂ O	0.05	0.82	0.74	5.16	0.27	4.29	1.14	5.16	1.04
Zinc Oxide	ZnO	0.03	0.02	0.04	0.32	0.39	0.41	0.53	0.01	1.84
Phos. Pentoxide	P ₂ O ₅	0.09	0.08	0.06	2.02	0.14	0.39	2.28	0.06	0.06
Sulfur Trioxide	SO ₃	0.14	0.27	0.18	0.21	0.12	0.14	0.08	0.37	0.16
Totals		99.16	98.53	98.74	99.04	98.67	98.81	98.97	98.82	98.80
										98.32

* All Paper Except Newspaper and Corrug. Cardboard, some smeared with Garbage.

The three glass samples indicated in Table No. 10 showed the lowest softening and fusion temperatures. Since glass is one of the principal constituents of the non-combustible portion of refuse, it should be borne in mind that glass is a viscous material which will deform and weld at temperatures of 1,300 degrees F. and higher.

With one exception, the ashes from the remaining refuse components also were found to soften at temperatures well below the 2,300 to 2,400 degree F. temperatures which have been observed in the fuel beds on the grates of conventional incinerators. Since all of the mineral matter does not fuse on the grates in the incinerator fire, it may be concluded that the glass and ash tend to gravitate to the grate surfaces where they are cooled by combustion air entering the furnaces through the grates.

Observations of refuse incinerator operations, along with consideration of metal melting points and other characteristics, as pointed out by Kaiser (1), lead to the following conclusions regarding metals occurring in refuse. Aluminum, with a melting point of 1,220 degrees F., will drip through at least some types of grates. Magnesium melts at 1,204 degrees F. and will burn with intense heat and light evolution as it runs through grates. Molten aluminum will react with hot mill scale to produce molten and superheated iron. Iron (m.p. 2,795 degrees F.), and iron oxides, FeO (m.p. 2,588 degrees F.), Fe_3O_4 (m.p. 2,800 degrees F.), and Fe_2O_3 (m.p. 2,849 degrees F.), do not normally melt in an incinerator fire. Soft solder (m.p. 428 degrees F. for 50-50 Pb-Sn), lead (m.p. 621 degrees F.), and zinc (m.p. 787 degrees F.) melt readily in incinerator fires. Zinc boils at 1,665 degrees F. and therefore will fume away if trapped in the fire. Tin melts at 449 degrees F. and oxidizes. The tin oxide powders off the tinned cans, but some of the tin is retained in the iron lattices.

The studies by Kaiser did not include the determination of chlorine content in ash.

Wet chemical analyses were run on slags taken from the walls of three refuse incinerators in New York City by Herbert (4). The results of these analyses are presented in Table No. 11. The balance to 100 per cent was not determined in these analyses, because of technical difficulties, but trace materials are believed to be present, including lead, manganese, copper, nickel, tin and chromium.

Slag samples were also investigated by Criss and Olsen (5) for chemical composition and fusion characteristics. Table No. 12 shows the average spectrochemical analyses of 25 slag samples from the New York, New Jersey and Connecticut areas in comparison with an average of the analyses made by Herbert (4). Table No. 13 shows the range of spectrochemical analyses of the slags tested compared to those tested by Herbert. In average composition, the major components of the two series of tests show reasonable correlation. The alkali averages in the Criss-Olsen tests were higher than

TABLE NO. 11

CHEMICAL ANALYSES OF SLAGS
FROM REFUSE INCINERATORS

	<u>Sample B</u>	<u>Sample D</u>	<u>Sample F</u>
SiO ₂	43.01%	49.91%	45.99%
Al ₂ O ₃	24.85	8.73	21.47
Fe ₂ O ₃	6.00	12.78	7.78
TiO ₂	3.31	2.40	3.00
CaO	9.28	11.03	9.50
MgO	2.47	2.54	2.65
Na ₂ O	3.28	3.31	3.16
K ₂ O	0.73	2.27	1.09
P ₂ O ₅	2.05	2.40	2.00
BaO	0.66	0.45	0.62
SO ₃	N.V.*	1.59	0.32
ZnO	1.17	2.49	0.46
Totals	97.95	99.90	98.04

*N.V. - None Visible on 1 Gram Sample.

TABLE NO. 12

AVERAGE SPECTROCHEMICAL ANALYSIS OF ALL
INCINERATOR SLAGS TESTED

	Average Analysis of 25 Slag Samples from N.Y., N.J., and Conn. Area	An Average of Herbert's Slag Samples from New York Area
Silica (SiO_2)*	44.73%	46.3%
Alumina (Al_2O_3)	17.44	18.35
Titania (TiO_2)	2.92	2.90
Iron Oxide (Fe_2O_3)	9.26	8.85
Copper Oxide (CuO)	T	N.R.
Calcium (CaO)	10.52	9.94
Magnesia (MgO)	2.1	2.54
Sulfate (SO_3)	3.69 (Av. 6)	0.96 (Av. 2)
Zinc Oxide (ZnO)	1.54 (Av. 6)	1.37
Lead Oxide (PbO)	T	N.R.
Phosphorus Pentoxide (P_2O_5)	1.52	2.15
Soda (Na_2O)	6.09	3.25
Potash (K_2O)	1.99	1.36
Lithia (Li_2O)	0.06	N.R.
Manganese Oxide (MnO_2)	0.29	N.R.
Barium Oxide (BaO)	T	0.58

* -All Samples Reported on a Calcined Basis.

T -Trace

N.R.-Not Reported.

TABLE NO. 13

RANGE OF SPECTROCHEMICAL ANALYSIS OF ALL
SLAGS TESTED

	Range of Analysis of 9 Incinerators in the N.Y., N.J., and Conn. Area (25 Samples)	A Range of Herbert's Analysis of 3 Incinerators in New York Area
Silica (SiO_2)	20.9 - 76.0%	43.01 - 49.91%
Alumina (Al_2O_3)	0.2 - 28.3	8.73 - 24.85
Titania (TiO_2)	0.33 - 4.9	2.40 - 3.31
Iron Oxide (Fe_2O_3)	1.8 - 40.0	6.00 - 12.78
Copper Oxide (CuO)	T	N.R.
Calcium (CaO)	7.3 - 17.0	9.5 - 11.03
Magnesia (MgO)	1.1 - 2.6	2.47 - 2.65
Sulfate (SO_3)	0.17 - 20.4 (Av. 6)	0.00 - 1.59
Zinc Oxide (ZnO)	0.20 - 6.3 (Av. 6)	0.46 - 2.49
Lead Oxide (PbO)	T	N.R.
Phosphorus Pentoxide (P_2O_5)	0.6 - 2.2 (Av. 6)	2.0 - 2.48
Soda (Na_2O)	0.6 - 11.6	3.16 - 3.31
Potash (K_2O)	0.3 - 8.1	0.73 - 2.27
Lithia (Li_2O)	0.03 - 0.13	N.R.
Manganese Oxide (MnO_2)	0.04 - 0.9	N.R.
Barium Oxide (BaO)	T	0.45 - 0.66
Change on Ignition	-2.9 - +5.7	N.R.

* - All samples reported on a calcined basis

T - Trace

N.R. - Not Reported

those found by Herbert. The ranges of composition as shown in Table No. 13 indicate the Criss-Olsen slags varied more widely than those of Herbert in essentially all constituents.

PART III

REFUSE SAMPLING AND ANALYSIS

GENERAL

All of the data presented in Part II of this report relate to raw refuse or to the ash and residue resulting from the incineration of raw refuse in conventional incinerators. Certain of the components of raw municipal refuse have no significant value as fuel. Some of these components may, if present in sufficient quantities, conceivably create conditions which could interfere with utility boiler operation. Consideration therefore must be given to the possibilities of removing such materials from the refuse and to determining the effects upon the physical and chemical characteristics of the remaining material which may be considered more suitable as fuel.

The great variety of sizes and shapes of the individual components of raw refuse makes it necessary to provide means to achieve a reasonably uniform particle size for the material to be fed to suspension-fired boilers. Once a relatively uniform particle size is achieved, it becomes possible to remove certain of the more undesirable components from the sized refuse by commercially available mechanical means which show promise of being adaptable for this purpose. The most accepted method of achieving uniform particle sizes for materials similar to refuse is the use of hammermills. Such mills will effect size reductions of normal refuse constituents to a degree which will permit the sized materials to be handled by several accepted methods.

Among those refuse components which either have no fuel value or which conceivably could cause operational difficulty in large scale boilers are metals, glass and dirt. Ferrous metals can be easily removed after milling by means of magnetic separators, which can reasonably be expected to remove between 90 and 95 per cent of the magnetic metal from the milled material. Glass and ceramic objects can be expected to be reduced by hammermills to small fragments, and a portion of these fragments can be removed by screening. The relatively large volumes of materials to be screened, together with the low bulk densities of the materials, makes necessary special consideration of screen design and application. Screening also will remove some dirt and small particles of combustible material. The removal of finely divided combustible material along with the inert material will detract from the fuel value of the remaining refuse. Screening may be justified only if the removal of glass and dirt particles will significantly reduce the possibilities of slagging and abrasion within the boilers.

SAMPLING PROGRAM

Examination of the data presented in Part II of this report will demonstrate that although the data are helpful in estimating the probable

characteristics of prepared refuse, they understandably do not provide the specific data which are of importance in anticipating design and operational requirements of facilities to handle the prepared material. Personnel of both the Union Electric Company and Combustion Engineering, Incorporated, who have designed and manufactured a number of the boilers in use in the Union Electric system, have agreed that further examinations of refuse produced locally would be of value if the refuse were prepared to simulate the material which would be fired to boilers under the adopted premises.

With the concurrence of the U.S. Public Health Service, arrangements therefore were made to sample and analyze several lots of refuse from representative parts of the City of St. Louis. It was recognized that the physical and chemical characteristics of refuse, or of fractions thereof, will vary from sample to sample, and that individual samples will not necessarily indicate the entire range of characteristics which should be expected. However, it was considered that the samples would provide at least some guidance as to certain of the problem areas anticipated in the processing, storage, transport, handling and firing of the prepared material.

The prepared refuse, as hereinafter referred to in this report, consists of particles of refuse with an approximate maximum dimension of one inch, with at least magnetic metal, and possibly glass and ceramic particles, removed to as great a degree as will be feasible with commercially available magnetic separators and screens. The removal of glass and ceramic particles must be considered with some reservation, since the effects of such materials upon the slagging and dust loading characteristics of boiler furnaces cannot be predicted with accuracy, and since the removal of such materials may also result in the removal of a valuable portion of the heat value of the prepared refuse. The objectives of the sampling and analyses were determined to be as follows:

1. To determine the approximate percentages of material which would be removed by magnetic separators and by screening.
2. To determine the percentage of raw refuse which would remain as potential fuel for suspension firing to boilers after the removal of magnetic metals and screenings.
3. To determine the bulk densities of the materials removed by magnetic separation and screening.
4. To determine the bulk densities of samples of the prepared refuse.
5. To determine the percentage of those particles of sufficient density and size in the prepared refuse which probably would fall to the bottom ash hopper of a utility boiler without being completely burned.

6. To acquire samples of the milled refuse (after magnetic separation) for shipping to screen manufacturers and other equipment manufacturers for tests.
7. To examine the prepared refuse with regard to potential problems of handling, storage and firing.
8. To determine the proximate and ultimate analyses of samples of the prepared refuse, together with determinations of ash analyses and the softening points of the resulting ash.

Arrangements were made for one of the City of St. Louis refuse collection vehicles to collect a partial load of raw refuse, by normal collection procedures, from designated typical parts of the City. The Williams Patent Crusher and Pulverizer Company of St. Louis, Missouri, provided complete cooperation in furnishing milling equipment, a magnetic separator and screening equipment, as well as the space necessary to process the refuse. The personnel manning the City collection truck were assigned to provide the labor necessary to handle the raw refuse and the prepared material. The procedures used in sampling the material and in preparation of the samples were agreed upon with Union Electric personnel.

SAMPLING PROCEDURE

First Sampling. The first sample was collected and processed on Wednesday, April 16, 1969. Although plans and arrangements were made well in advance, considerable time was lost in developing and modifying procedures and techniques to suit the specific circumstances.

A City of St. Louis refuse collection vehicle collected a load of 1,400 pounds of domestic mixed refuse by normal collection procedures, and delivered the load to the plant of the Williams Patent Crusher and Pulverizer Company. The load was collected in the O'Fallon Park area of the north-central part of the City, and included refuse produced since Friday of the preceding week. Rain had fallen on Sunday and Monday of this period. Free water spilled from the truck as the load of refuse was dumped.

The entire load of refuse was milled in a single pass through a Model 30KS Williams Hammermill powered by a 210 horsepower diesel engine with a V-belt drive. The grate bar spacing provided about one-third of the bars with 1/2 inch spacing, one-third of the bars with 3/4 inch spacing, and one-third of the bars with a 1 inch spacing. The initial speed of the hammermill was 1,800 rpm. This speed, together with the relatively small feed hopper on the mill, caused a large proportion of the raw refuse (possibly two-thirds) to be blown out of the feed hopper opening. After a brief run at the higher speed, the machine was slowed down to about 900 rpm and

the feed hopper was reversed. These changes resulted in improvement of the operation so that very little material failed to pass through the mill. The speed of the mill was subsequently increased to 1,200 rpm, still with satisfactory operation.

The shredded material discharged from the mill was conveyed by a belt conveyor to an 8-foot by 8-foot wooden bin. The material collected was mixed and quartered. One quarter of the entire sample was weighed and conveyed past a magnetic pulley for separation of the magnetic metal. The magnetic fraction was collected in a drum, measured and weighed. The remainder of the quarter, with magnetic material removed, was again mixed and quartered. Two of the quarters were placed in drums, weighed and shipped to two screen manufacturers for testing. One drum was shipped to Combustion Engineering, Inc., for inspection and testing.

One sample of about one cubic foot in volume was shipped to the Commercial Testing and Engineering Company in Chicago, Illinois, for proximate and ultimate analyses and for determination of the composition and characteristics of the ash resulting from its combustion. This latter sample was screened, with the fractions retained on 1/8-inch mesh and passing through 1/8-inch mesh being submitted as the samples on which the analyses were to be performed.

One portion of the milled material was retained to determine an approximation of the screen size potentially applicable for the process. Fractions of this portion were processed through screens made available by the Williams Patent Crusher and Pulverizer Company.

Due to unforeseen delays and necessary modifications in equipment and procedures, it was not possible to complete all of the experimentation during the day the sample was milled. As a result, the screening experiments had to be conducted on the following day. Despite reasonable precautions, it is believed the screening experiments, together with the extra handling, resulted in considerable moisture loss.

Visual observation of the material discharged from the hammermill indicated that the nominal maximum particle size was about 3/4 inch. The particles seemed damp to the touch, but it was concluded by all parties observing the milling, including representatives of the Union Electric Company and Combustion Engineering, Inc., that the material should be readily combustible in a suspension-fired furnace. It appeared probable that the milling operation, with its violent agitation and air circulation, caused an appreciable reduction in the moisture content of the particles, and that further handling of the material in conveying and processing operations would be responsible for an even further reduction in moisture. The conclusion may reasonably be made that some reduction in the moisture content of wet refuse could be expected even in large scale processing facilities.

The material discharged from the hammermill was light and fluffy, despite the apparently high moisture content. Bulk density of the material, without compaction, was found to be about 9.4 to 11.3 pounds per cubic foot before removal of the magnetic material, and about 8.5 to 10.0 pounds per cubic foot after such removal. There was no indication that pneumatic feeding and conveying of the milled material would create significant problems. The material compacted readily, but when dumped from a container tended to expand without special effort being required.

The fraction of magnetic material removed was found to be about 7.3 per cent by weight of the milled material, with a bulk density of about 27.4 pounds per cubic foot. These metal particles consisted principally of irregularly shaped balls and crumpled shreds of jagged metal with considerable voids, which accounts for its low bulk density.

The particle size achieved by the mill, because of the rather small openings provided by the grate bars, was about 3/4 inch, with a relatively small percentage of the particles of greater size. The results obtained from the laboratory screens in this case are not deemed necessarily typical of those to be expected in a full scale application using commercially available screening systems. The percentage of smaller particles was greater than anticipated, and raised the question as to whether the grate bar spacing used in this run of the mill was too small. Discussion with personnel of the Williams Patent Crusher and Pulverizer Company resulted in the conclusion that the grate bar spacing should be increased in further samplings.

Second Sampling The second sample was collected and processed on Tuesday, April 29, 1969. The sample, consisting of about 500 pounds of mixed domestic refuse, was collected from the Fairgrounds Park area of North St. Louis. About 1/4 inch of rain fell during one of the days over the previous weekend. Visual examination indicated this sample to be considerably drier than the first sample.

The raw refuse was processed through the same mill at the Williams Patent Crusher and Pulverizer Company, with the mill operating at 1,200 rpm. The grate bars were changed for this run to provide less size reduction. One-half of the bars provided 1-inch openings and the other half provided 1-1/2-inch openings. A new feed hopper also was installed so as to provide better containment of the material being fed. A belt conveyor was used for feeding, but manual assistance was required for the more bulky items.

After milling, the entire lot was passed over a magnetic pulley. Uncompacted densities of several samples before magnetic separation indicated bulk densities of only 4.5 to 4.75 pounds per cubic foot. These densities, almost half of those indicated from the first sampling, apparently were due to the dryness of the raw material. Experiments on one cubic foot samples showed that the bulk densities at least doubled under a pressure equivalent

to 47.5 pounds per square foot. When pressure was released, only a minor rebound was apparent. When the container was emptied, the milled material appeared to regain its light and fluffy consistency with very little agitation. A compaction test performed on one sample with magnetic materials removed resulted in a density of 14.4 pounds per cubic foot with an applied pressure equivalent to 230 pounds per square foot. Further experiments of compaction were planned for the third sampling. Essentially no difference in bulk density of the milled refuse was indicated after removal of magnetic metal. The bulk density of the magnetic metal removed was found to be about 28 pounds per cubic foot, and the magnetic metal to be about 5.0 per cent by weight of the total milled material.

Some moisture loss again was indicated in milling and processing

Screening tests made from material processed from the second day of sampling indicated somewhat larger particle sizes, in that more material was retained on a 1-inch screen and less material was passed through a finer screen.

Third Sampling. The third sample was collected and processed on Friday, May 9, 1969. About 1,000 pounds of domestic refuse was collected from the north-central part of the City. This sample reflected refuse produced on the preceding Wednesday and Thursday. On both of these days the weather was cloudy with rain showers. On Friday, the day of sampling, there was a strong wind, which prevented the use of the magnetic pulley for separating magnetic materials from the milled refuse. The raw refuse was milled in the same unit and with the same grate spacing as in the second sampling.

Loose densities of one cubic foot samples varied from 5.5 to 8.7 pounds per cubic foot, without removal of magnetic materials. Loose density of the same material in 1/2 cubic yard lots (measured in a 3x3-foot by 18-inch high box) was found to be 10.5 to 10.8 pounds per cubic foot. Loose density of a one cubic foot sample with magnetic material removed was found to be about 4.5 pounds per cubic foot. The magnetic material (removed in this test by a hand magnet) was found to be between 6.1 and 9.4 per cent of the samples.

Compaction tests performed on material containing magnetic material indicated that densities between 16.5 and 24.6 pounds per cubic foot could be achieved by application of a force equivalent to about 140 pounds per square foot. Application of an additional 200 pounds per square foot in one test increased the density only slightly, from 24.6 to 26.1 pounds per cubic foot.

SCREENING TESTS ON COMMERCIALY AVAILABLE SCREENS

Tests of samples of milled refuse with magnetic materials removed, were performed at the test facilities of the Orville Simpson Company and the

W. S. Tyler Company, regarding the feasibility of screening the milled material on commercially available equipment. The tests demonstrated the difficulties to be anticipated in the screening of large volumes of materials with low bulk densities. Even on the test facilities, there was some indication of blinding of the screen surfaces, and of the necessity of maintaining generously proportioned chutes and channels to prevent blockage of the flow of material.

The screening tests in each case indicated very large screen areas to be required. In the case of the Orville Simpson equipment, a total of about 800 square feet of screen area was indicated for an assumed production rate of 95 tons per hour. About 900 square feet was indicated to be required by the Tyler equipment. Screen areas of this magnitude would result in multiple screening units being necessary for the assumed production rate. Eight units, each with an area of about 100 square feet, would be required for the Orville Simpson equipment, and ten units, each with an area of about 96 square feet, would be required for the Tyler equipment to achieve the 95 tons per hour production rate. In addition to the screens, a complex system of chutes and conveyors would be required to distribute the milled material to the screens as well as to collect the various fractions and convey them to appropriate points.

MATERIALS EXPECTED TO FALL TO BOTTOM ASH HOPPER

Samples taken during each of the three sample runs were hand-sorted to determine the relative quantities of material which could be expected to fall to the bottom ash hopper of a boiler. The hand-sorting procedure cannot be expected to be accurate, because of obvious limitations. For example, the sorting was dependent upon the judgment of the sorters, which could not take into account the aerodynamic properties of the particles but had to be confined to visual determination of the sizes and densities of the individual particles. Further, only heavy particles over 1/10 inch in size were separated, and there certainly would be smaller particles of glass and ceramic materials which would fall to the ash hopper. The heavy material separated from the first sample was about 12 per cent by weight of the sample, for the second sample about 8 per cent, and for the third sample about 6 per cent. It is estimated that an additional 2 to 4 per cent of each sample could also reasonably be expected to fall to the ash hopper.

ANALYTICAL RESULTS

The Commercial Testing and Engineering Company, in Chicago, Illinois, performed the analytical work on the samples submitted. Magnetic materials were removed from all samples. Proximate and ultimate analyses were performed on both fractions of each sample. One fraction of each sample consisted of those particles retained on a 6-mesh sieve (1/8-inch openings), and the other fraction consisted of those particles passing through a 6-mesh sieve. Mineral analyses of the ash of each fraction also were performed,

along with determinations of ash fusion temperatures. The analytical results are presented in Table No. 14. The analyses listed under "Weighted Composite" were computed from the analyses of the two fractions of each sample.

The calorific values of the as-received material in those fractions without fines varied from 4,521 to 5,842 Btu per pound. The as-received calorific values of the screenings varied from 2,145 to 3,911 Btu per pound. The weighted composite samples of both fractions showed computed as-received calorific values of 4,171 to 5,501 Btu per pound.

The percentages of ash of the as-received samples were in the 25 to 26 per cent range for two of the samples, but on the order of only 10 per cent for the third sample. Although this latter low value may be found for short periods, it is believed that the lower percentage is not realistic for typical municipal refuse, and that the 25 to 26 per cent values are within the range to be expected. It is of interest to note that the percentage of ash in typical coals used by the Union Electric Company, as presented in Table No. 15, is in the 10 to 15 per cent range. Of further interest is the relatively high fusion temperature of refuse ash, which is remarkably similar to that of coal ash.

Even the highest of the sulfur percentages of the three refuse analyses is only a fraction of the corresponding value for coal. The chlorine contents of the refuse samples in all cases were higher than for the coals as shown in Table No. 15. However, two of the coals show a chlorine content of the same order of magnitude as those of refuse.

At the suggestion of Combustion Engineering, Inc., and Union Electric Company personnel, the laboratory also was requested to determine the presence of metals in the ash, such as zinc, lead, copper, vanadium, iron, tin and lithium. Qualitative spectrographic analyses and concentrational estimates of the detected constituents are tabulated in Table No. 16.

The lack of uniformity of the analyses of the three samples is to be expected. Considering the heterogeneous nature of refuse, and the difficulty of obtaining truly representative samples, the differences between the laboratory results are not regarded as extraordinary.

TABLE NO. 14

PROXIMATE, ULTIMATE AND MINERAL ANALYSES
CITY OF ST. LOUIS REFUSE

	First Sample - (4/16/69)				Second Sample - (4/29/69)				Third Sample - (5/9/69)			
	Over 1/8 Inch (80.98%)		Under 1/8 Inch (19.02%)		Over 1/8 Inch (82.35%)		Under 1/8 Inch (17.65%)		Over 1/8 Inch (72.00%)		Under 1/8 Inch (28.00%)	
	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry
Proximate Analyses												
Moisture	29.50	-	16.92	-	20.52	-	15.82	-	31.97	-	29.68	-
Ash	22.03	31.25	47.27	56.67	3.08	3.88	39.08	46.43	21.52	31.64	36.19	51.46
Volatiles	48.46	66.74	32.63	39.28	59.13	74.39	42.72	50.75	44.37	65.22	17.21	24.48
Fixed Carbon	0.01	0.01	3.20	3.85	17.27	21.73	2.86	2.82	2.14	3.14	16.92	24.06
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Btu per Pound	4,521	6,413	3,507	4,221	5,842	7,350	3,911	4,646	4,959	7,289	2,147	3,051
Sulfur	0.17	0.24	0.27	0.32	0.16	0.20	0.77	0.91	0.40	0.59	0.16	0.23
Ultimate Analyses												
Moisture	29.50	-	16.92	-	20.52	-	15.82	-	31.97	-	29.68	-
Carbon	25.56	36.29	21.30	25.64	35.73	44.95	22.93	27.24	26.48	38.92	15.66	22.27
Hydrogen	3.59	5.09	2.94	3.54	5.07	6.38	3.03	3.67	3.89	5.72	2.06	2.93
Nitrogen	0.24	0.34	0.45	0.54	0.30	0.38	0.71	0.84	0.13	0.19	0.35	0.50
Chlorine	0.13	0.18	0.12	0.15	0.13	0.13	0.26	0.45	0.37	0.54	0.18	0.25
Sulfur	22.03	31.25	47.27	56.67	3.08	3.88	39.08	46.43	21.52	31.64	36.19	51.46
Oxygen	18.76	26.61	10.75	12.94	23.63	35.04	17.22	20.46	15.24	22.40	15.72	22.36
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mineral Analyses (Ig. Basis)												
Phos. Pentoxide	1.22	0.44	0.44	1.07	1.09	45.55	0.71	1.02	6.27	0.61	0.61	4.69
Silica	58.37	64.73	64.73	60.07	64.68	64.68	64.68	48.93	46.85	62.36	62.36	51.18
Ferric Oxide	6.10	5.38	5.38	5.96	3.53	3.53	3.53	3.50	5.59	6.76	6.76	5.92
Alumina	14.64	9.74	9.74	13.72	11.12	11.12	11.12	10.12	6.70	4.28	4.28	5.02
Titanium	1.82	0.68	0.68	1.66	0.98	0.98	0.98	0.88	0.81	0.57	0.57	0.74
Lime	7.34	8.38	8.38	7.54	13.69	13.69	12.16	13.46	20.44	12.40	12.40	18.19
Magnesia	1.91	1.93	1.93	1.91	1.28	1.28	1.28	1.28	1.02	1.44	1.44	1.14
Sulfur Trioxide	1.92	1.51	1.51	1.84	14.44	14.44	3.70	12.54	4.52	2.35	2.35	3.91
Potassium Oxide	2.73	2.02	2.02	2.59	3.04	3.04	1.12	2.70	1.78	1.02	1.02	1.57
Sodium Oxide	3.33	4.83	4.83	3.62	4.36	4.36	6.07	4.66	5.12	8.07	8.07	5.95
Undetermined	0.02	0.36	0.36	0.08	0.92	0.92	0.88	0.91	0.90	0.14	0.14	0.69
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Fusion Temp. of Ash												
Initial Deformation	1,920	2,040	1,330	2,050	1,980	2,030	1,890	2,030	1,960	2,050	2,070	2,100
Softening (Hw)	2,200	2,260	2,190	2,260	2,270	2,330	2,360	2,420	2,300	2,420	2,460	2,390
Softening (H= 1/2 W)	2,200	2,290	2,210	2,290	2,290	2,360	2,390	2,450	2,320	2,450	2,490	2,420
Fluid	2,410	2,480	2,360	2,630	2,400	2,500	2,540	2,590	2,530	2,700	2,530	2,540

TABLE NO. 15
TYPICAL ANALYSES OF COAL
USED IN UNION ELECTRIC COMPANY PLANTS

TYPE OF COAL POINT OF USE	Washed		Washed		Meramec		Portage Des Sioux		R.O.M.	
	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry
Proximate Analysis										
Moisture - %	6.20	-	10.23	-	10.00	-	11.87	-	7.99	-
Ash - %	9.77	10.37	10.14	11.29	10.83	12.03	8.86	10.05	12.84	13.95
Volatile - %	40.03	42.68	37.60	41.89	34.03	37.81	34.92	39.63	34.10	37.06
Fixed Carbon - %	44.04	46.95	42.03	46.82	44.14	50.16	44.35	50.32	45.07	48.99
Heat Units	11,931	12,720	11,414	12,715	11,258	12,509	11,313	12,839	11,379	12,367
Sulfur - %	3.93	4.19	3.06	3.41	3.23	3.59	3.36	3.83	2.63	2.86
Alkalies as Na ₂ O - %	0.14	0.15	0.18	0.20	-	-	-	0.15	-	0.30
Ultimate Analysis										
Moisture - %	6.20	-	10.23	-	10.00	-	11.87	-	7.99	-
Carbon - %	66.18	70.55	61.81	71.08	61.29	68.10	61.86	70.33	64.40	69.99
Hydrogen - %	5.41	5.03	5.58	4.95	4.49	4.99	4.51	5.12	4.32	4.69
Nitrogen - %	1.28	1.36	1.31	1.46	0.83	0.92	0.71	0.83	0.96	1.07
Chlorine - %	0.02	0.03	0.04	0.04	0.05	0.06	0.04	0.05	0.29	0.32
Sulfur - %	3.93	4.19	3.06	3.41	3.23	3.59	3.36	3.83	2.63	2.86
Ash - %	9.77	10.37	10.14	11.29	10.83	12.03	8.86	10.05	12.84	13.95
Oxygen - % (Diff.)	13.44	8.47	16.10	7.81	9.28	10.31	8.63	9.79	6.55	7.12
Analysis of Ash										
Phos Pentoxide - P ₂ O ₅	0.20	-	0.18	-	0.08	-	-	-	0.21	-
Silica - SiO ₂	45.59	46.93	45.52	45.52	45.52	45.52	45.52	45.52	45.52	45.52
Ferric Oxide - Fe ₂ O ₃	25.29	15.51	15.51	15.51	15.51	15.51	15.51	15.51	15.51	15.51
Alumina - Al ₂ O ₃	16.54	18.12	18.12	18.12	18.12	18.12	18.12	18.12	18.12	18.12
Titanium - TiO ₂	0.81	1.01	1.01	1.01	0.85	0.85	0.85	0.85	0.85	0.85
Lime - CaO	2.13	5.42	5.42	5.42	6.31	6.31	6.31	6.31	6.31	6.31
Magnesia - MgO	0.90	0.92	0.92	0.92	0.80	0.80	0.80	0.80	0.80	0.80
Sulfur Trioxide - SO ₃	1.41	4.26	4.26	4.26	6.28	6.28	6.28	6.28	6.28	6.28
Potassium Oxide - K ₂ O	1.78	1.78	1.78	1.78	1.70	1.70	1.70	1.70	1.70	1.70
Sodium Oxide - Na ₂ O	0.30	0.62	0.62	0.62	0.46	0.46	0.46	0.46	0.46	0.46
Undetermined	5.05	5.25	5.25	5.25	0.39	0.39	0.39	0.39	0.39	0.39
Fusion Temperatures of Ash - ° F										
Init Def.	1,940	2,020	1,960	2,050	2,010	2,275	1,985	2,360	2,060	2,360
Softening (H = W)	1,980	2,440	2,100	2,120	2,200	2,455	2,085	2,450	2,210	2,450
Fluid. Temp.	2,180	2,480	2,220	2,260	2,215	2,470	2,185	2,540	2,240	2,540
Sulfur Forms	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry
Pyritic	1.62	1.84	1.17	1.30	1.58	1.76	1.62	1.84	1.62	1.84
Sulfate	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Organic	2.08	2.22	1.45	2.07	1.62	1.80	1.62	1.80	1.62	1.80
Total	3.93	4.19	3.06	3.41	3.23	3.59	3.36	3.83	2.63	2.86

TABLE NO. 14

QUALITATIVE SPECTROCHEMICAL ANALYSES AND
CONCENTRATIONAL ESTIMATES OF DETECTED CONSTITUENTS
(Ranges of Percentages)

	First Sample		Second Sample		Third Sample	
	Over 1/8-Inch	Under 1/8-Inch	Over 1/8-Inch	Under 1/8-Inch	Over 1/8-Inch	Under 1/8-Inch
Silicon	5.0	to 50.0	5.0	to 50.0	3.0	to 30.0
Calcium	5.0	to 50.0	5.0	to 50.0	5.0	to 50.0
Aluminum	3.0	to 30.0	2.0	to 20.0	2.0	to 20.0
Iron	2.0	to 20.0	1.0	to 10.0	0.5	to 5.0
Sodium	1.0	to 10.0	0.5	to 5.0	0.5	to 5.0
Magnesium	0.5	to 5.0	0.3	to 3.0	0.5	to 5.0
Titanium	0.5	to 5.0	0.2	to 2.0	0.5	to 5.0
Potassium	0.3	to 3.0	0.1	to 1.0	0.2	to 2.0
Manganese	0.3	to 3.0	0.1	to 1.0	0.1	to 1.0
Lead	0.03	to 0.3	0.01	to 0.1	0.1	to 1.0
Barium	0.02	to 0.2	0.05	to 0.5	0.1	to 1.0
Strontium	0.02	to 0.2	0.02	to 0.2	0.2	to 2.0
Tin	0.01	to 0.1	0.005	to 0.05	0.05	to 0.5
Copper	0.01	to 0.1	0.01	to 0.1	0.01	to 0.1
Zirconium	0.01	to 0.1	0.01	to 0.1	0.01	to 0.1
Nickel	0.005	to 0.05	0.003	to 0.03	0.005	to 0.05
Chromium	0.005	to 0.05	0.003	to 0.03	0.001	to 0.01
Boron	0.003	to 0.03	0.005	to 0.05	0.005	to 0.05
Vanadium	0.003	to 0.03	0.005	to 0.05	0.001	to 0.01
Cobalt	0.001	to 0.01	0.0005	to 0.005	0.003	to 0.03
Molybdenum	N.R.	N.R.	0.0002	to 0.002	Tr.	Tr.
Silver	N.R.	N.R.	0.001	to 0.01	N.R.	N.R.
Phosphorus	N.R.	N.R.	0.0001	to 0.001	N.R.	N.R.
Zinc	N.R.	N.R.	N.R.	N.R.	Q-0.3	to 3.0-Q

Tr. = Trace
Q = Questionable if present
N.R. = Not reported

PART IV

EXISTING BOILER FACILITIES IN UNION ELECTRIC COMPANY SYSTEM

GENERAL

The Union Electric Company has steam generating units dating back to the year 1910. The Company has eight stations in the immediate vicinity of the St. Louis area, enumerated as follows:

- Mound Street Plant
- Ashley Street Plant
- Cahokia Plant
- Venice Plant No 1
- Venice Plant No 2
- Meramec Plant
- Sioux Plant
- Labadie Plant

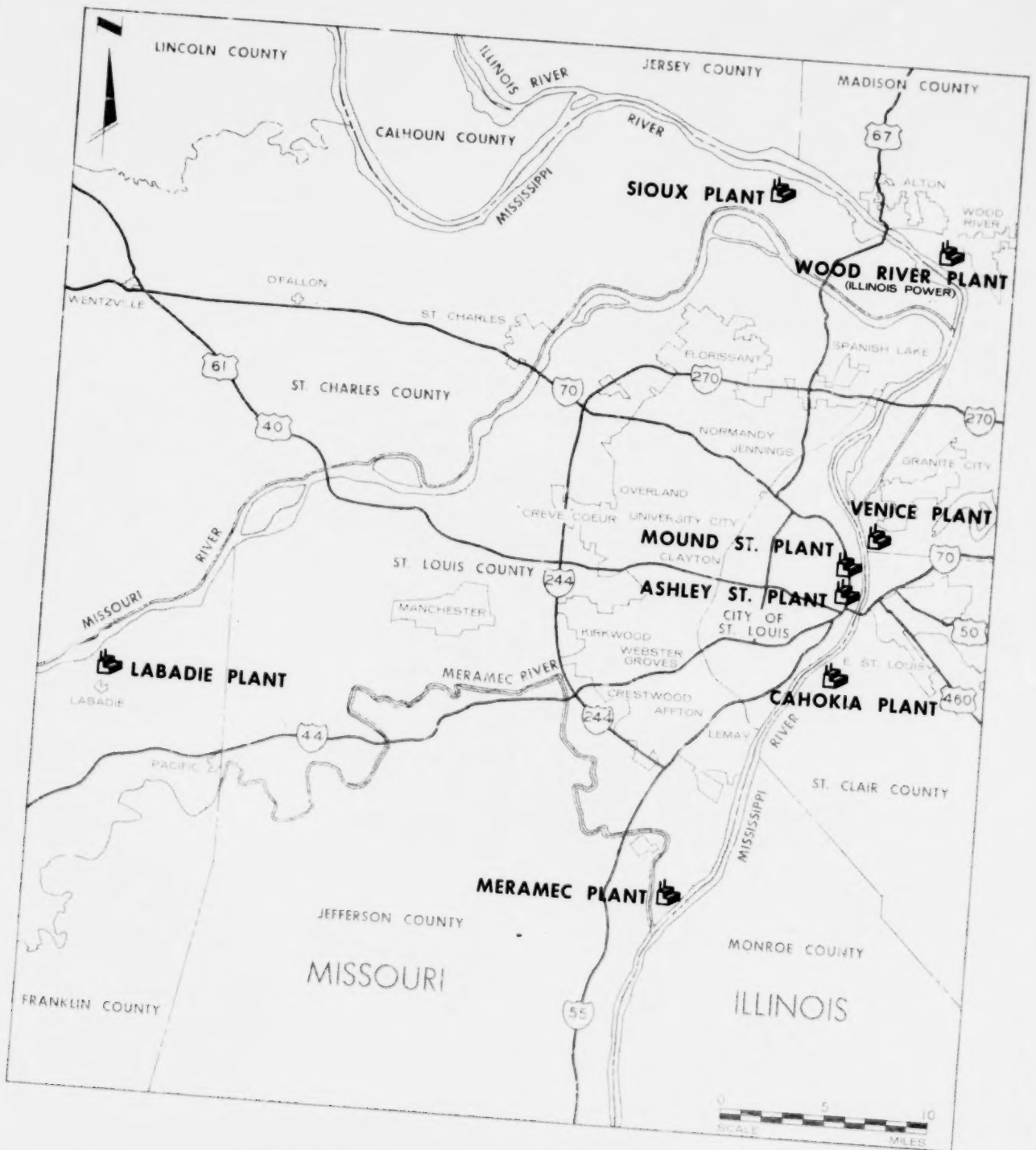
The plants have varied types of boilers of different sizes, some fired with pulverized coal, one with crushed coal and the remainder with oil or gas. Some of the boilers are equipped for firing combinations of fuels. Brief descriptions of the boilers included in the eight plants are summarized in the following paragraphs. Their locations relative to the St. Louis metropolitan area are shown on Figure No. 1.

MOUND STREET PLANT

This plant, located near the Mississippi River north of downtown St. Louis, is the oldest in the system. It has a very low use factor and is understood to be close to retirement. It presently is used only during peak periods of electricity production, and is not considered appropriate as a facility in which significant benefits could be achieved by burning refuse as a supplementary fuel.

ASHLEY STREET PLANT

This plant is located near the Mound Street Plant. It is equipped with five Riley Stoker Corporation front-fired boilers. Also one of the oldest facilities in the Union Electric System, it is used basically as a plant for furnishing steam for heating in the downtown area of the City of St. Louis. It is operated mostly in winter months, and very little during the summer. Its use factor is low, on the order of 25 per cent, and therefore it normally would not be considered attractive for burning refuse. The net plant heat rate for its turbine generators is relatively high, and the



**LOCATION OF UTILITY POWER PLANTS
IN VICINITY OF ST. LOUIS, MISSOURI**
(ALL PLANTS ARE OWNED AND OPERATED BY UNION ELECTRIC CO. UNLESS OTHERWISE NOTED)

electric generating units are not operated unless the demand for electricity is at a maximum. However, increasing demands for steam in the downtown area of the City could increase the attractiveness of burning prepared refuse in this plant.

CAHOKIA PLANT

This facility is located in the Village of Sauget (formerly Monsanto), Illinois, across from the City of St. Louis on the east bank of the Mississippi River. It includes a total of 22 relatively small boiler units, and if refuse were used as a supplementary fuel at this plant, the distribution of the refuse over the relatively large number of units could pose problems of materials handling. The use factor of this plant is very low, about 5 to 10 per cent. The plant requires numerous improvements before its use factor could be improved significantly. Its net plant heat rate is high, ranging between 16,000 and 20,000 Btu per kwh. For these reasons the plant is not considered attractive for burning refuse.

VENICE PLANT NO. 1

This plant is located in Venice, Illinois, on the Mississippi River across from the north part of the City of St. Louis. It is used as a peaking plant, normally for only 50 to 100 hours per year. Its boilers are relatively small and not suitable for burning refuse in large quantities.

VENICE PLANT NO. 2

This plant is located adjacent to Venice Plant No. 1. It consists of four sections, each of which includes two boilers of identical type. All turbine generators at this plant are of the non-reheat type. The net plant heat rate for this facility ranges between 12,400 and 13,400 Btu per kwh for the entire plant.

Section No. 1 The first section of Venice Plant No. 2 includes two Combustion Engineering Company front-fired boilers. Each boiler is equipped with six burners, with two burners on each of three levels, to burn either pulverized coal or gas. With some modifications these boilers are considered to have possibilities for burning prepared refuse. Their use factor is low and the net plant heat rate is high. A reduction of about 20 per cent in fuel cost would be necessary for these boilers to become attractive as base load units. They are each designed to burn about 26 tons per hour of coal having a calorific value of 10,500 Btu per pound at full load.

Section No. 2 The second section of this plant includes two front-fired Riley Stoker Corporation boilers, with three burners in each of two

levels, equipped to burn either pulverized coal or gas. The comments relating to Section No. 1 of this plant generally apply here as well. These boilers are each designed to burn about 26 tons per hour of coal having a fuel value of 10,500 Btu per pound at full load.

Section No. 3. The third section includes two Combustion Engineering Company boilers identical with those in the first section of this plant. The same comments apply.

Section No. 4. The fourth section of Venice Plant No. 2 includes two Babcock and Wilcox boilers equipped for top vertical firing. They are each provided with eight burners in the top of the boilers set in a single row, and are equipped to burn only pulverized coal. The same general operating characteristics apply to these boilers as to Sections 1, 2 and 3. These boilers are designed to burn about 53 tons per hour of coal having a fuel value of 10,700 Btu per pound at full load.

MERAMEC PLANT

The Meramec plant is located in Missouri on the west bank of the Mississippi River about 15 miles south of the City of St. Louis. It consists of four units.

Unit No. 1 Unit No. 1 includes a Combustion Engineering Company pulverized coal or natural gas fired boiler of the reheat type, with radiant type water walls. The furnace is equipped with four burners in each of the four corners, for tangential firing. At full load the furnace will burn about 57.5 tons per hour of coal with a heating value of 10,500 to 11,000 Btu per pound, or an equivalent amount of natural gas. The net plant heat rate for this unit ranges between about 9,600 and 10,700 Btu per kwh, and an improvement of about 5 per cent in the net plant heat rate would make this unit competitive with newer facilities as a base load unit. Its use factor presently is about 70 per cent, which under anticipated conditions will decrease to about 30 per cent as newer and larger base load units are placed in service.

Unit No. 2 This unit is a twin of the No. 1 unit, with the same characteristics. It is equipped with plant scale experimental facilities (the alkaline earth process) for reducing the emission of sulfur dioxide in flue gases. This experimental work is still proceeding.

Unit No. 3. Unit No. 3 of the Meramec plant includes a Foster Wheeler Corporation twin furnace of the radiant type, with dual circulation. The boiler is front-fired, with four burners in each of three horizontal rows, equipped to burn either pulverized coal or gas. At full load the twin furnaces will burn about 116 tons per hour of coal with a fuel value of about 10,650 Btu per pound, or an equivalent amount of natural gas. The

net plant heat rate for this unit, together with Unit No. 4, is on the order of 9,500 Btu per kwh, and its use factor is presently about 75 per cent.

Unit No. 4. This unit includes a Foster-Wheeler Corporation single divided furnace, of the radiant type, front-fired, equipped to burn pulverized coal. The furnace has six burners in each of three horizontal rows, and at full load will burn about 143 tons per hour of coal with a fuel value of 10,650 Btu per pound. The net plant heat rate for this unit, together with Unit No. 3, is about 9,500 Btu per kwh, and its use factor is on the order of 75 per cent.

SIOUX PLANT

The Sioux Plant is located in St. Charles County, Missouri, on the west bank of the Mississippi River about 19 miles north of the City of St. Louis. This plant is comprised of two identical Babcock and Wilcox Company units. Each unit includes a cyclone-fired, pressurized furnace, with ten cyclone burners, five on each of the front and back boiler walls, equipped to burn crushed coal. At full load each unit will burn about 208 tons per hour of coal, with a fuel value of 11,300 Btu per pound. The temperature in the cyclone burners is in excess of 3,000 degrees F., and molten slag is discharged from the cyclones and the furnaces to water-filled tanks, where the slag is solidified. The cyclones are operated under an internal pressure of about 54 inches of water. The net plant heat rate of these two units is in the range of 9,200 Btu per kwh. Both units are base loaded and will continue to be base loaded for the foreseeable future.

LABADIE PLANT

This plant presently is under construction. It is located on the south bank of the Missouri River in Franklin County, Missouri, about 35 miles west of the City of St. Louis. When completed, the plant will include four identical boilers of the controlled circulation type. The first unit is scheduled for completion in 1970 and the last unit in 1973. All units will burn pulverized coal, and are designed to burn about 238 tons per hour in each boiler, with a heating value of 11,500 Btu per pound. The boilers will be corner-fired, with five burners in each of the four corners. The projected net plant heat rate for these units is about 9,300 Btu per kwh.

FUTURE FACILITIES

Forward planning of the Union Electric Company includes plans for future large scale coal-fired boiler facilities within 50 miles of the City of St. Louis. The types of boilers to be used in these future facilities have not yet been determined.

PART V

EXISTING FACILITIES APPLICABLE FOR BURNING PREPARED REFUSE IN BOILERS

FACILITIES CONSIDERED

Discussions with Union Electric Company engineers have resulted in the conclusion that it would be reasonably feasible to fire small percentages of prepared refuse to the existing boilers at Venice Plant No. 2, at the Meramec Plant, at the Sioux Plant, and at the new boilers presently under construction at Labadie, in Franklin County, Missouri. All of the existing boilers would require modification to permit the firing of prepared refuse, such modifications being minor in some cases, major in others. Among the factors given consideration in determining the relative feasibility of the proposed process are the net plant heat rates, the sizes of the units, the locations and spacings of the burners, the use factors of the units, existing operating problems and the possibilities of achieving the greatest long-term benefits to both the Union Electric Company and the City of St. Louis.

The Venice Plant No. 2 has been in service for over 25 years. The net plant heat rate is relatively high at this facility, ranging between 12,300 and 12,400 Btu per kwh. The use factor of the boilers is relatively low, and a reduction of about 20 per cent in fuel cost probably would be necessary for the boilers to become attractive as base load units. The first three sections of the plant, each including two boilers, are front-fired. All six of these boilers are each capable of consuming about 26 tons per hour of pulverized coal. The boilers are each equipped with only six burners, and if one of these were converted to firing prepared refuse, flexibility of operation might not be as great as desired. If it were determined that one or more of these units could be used for burning refuse as a supplementary fuel, it probably would be desirable to install new burners for refuse only. It appears likely that such new burners would require revision of the tubes in the boiler walls. Further, the quantity of refuse to be fired to one of the units would be on the order of only 5 to 7 tons per hour, and such small quantities would not result in as attractive an economic advantage as for larger quantities. For purposes of this report, at least, it is concluded that these boilers are not as promising as others in the Union Electric Company System.

Units No. 7 and 8 at Venice Plant No. 2 are top-fired boilers, the only two of this type in the Union Electric Company System. Each of these units is capable of burning over 50 tons of pulverized coal per hour. They each are equipped with eight burners in the tops of the furnaces, and the gas flow in the furnaces is downward, which may be an attractive feature. However, since these units are considered unusual, it is concluded that full

benefit could not be obtained in units of this type for evaluating the firing of prepared refuse as supplementary fuel.

The cyclone-fired furnaces at the Sioux Plant have features which appear attractive for burning controlled percentages of prepared refuse. The sizing of material fired to such units may not be as critical as in other types of boilers, since the coal fired to the cyclones is required to be crushed but not pulverized, a distinct advantage. The temperatures achieved in the cyclones are in excess of 3,000 degrees F., which would be sufficient to melt essentially all materials in raw refuse. This feature could obviate the removal of metals and other non-combustible materials from the material fired, and at least theoretically, would simplify the bottom ash-handling process, as well as eliminate the necessity of separate disposal of the non-combustible materials. However, the boilers are pressurized, with pressures in excess of 50 inches of water existing in the cyclones, and the operating problems resulting from pressurization and from certain other features lead to the conclusion that the imposition of additional variables on their operation cannot be condoned at this time.

Unit No. 3 at the Meramec Plant includes a front-fired twin furnace boiler. Operation of this unit is not deemed typical of the other boilers in the system, and it is concluded that it would not be appropriate to consider this boiler for burning refuse as a supplementary fuel, at least at this stage of investigation.

Unit No. 4 at the Meramec Plant includes a front-fired divided furnace. This unit could possibly be modified to permit the burning of refuse. A preliminary scrutiny by the Foster Wheeler Corporation indicates that it could be feasible for two new burner ports to be installed in each of the three sections of the furnace by cutting into the water wall. Modifications of this extent are not regarded as being completely desirable at this stage of investigation.

The two existing boilers which appear to have the greatest applicability for firing prepared refuse with the least modifications are Meramec Units No. 1 and 2. These boilers are tangentially (corner) fired, each equipped with four burners in each corner. Unit No. 2 has been fitted with full scale facilities for reducing sulfur dioxide emissions by the alkaline earth process. Experimental work in air pollution control currently is proceeding in Unit No. 2, and it is not considered advisable to introduce additional potential variables into the operation of the boiler at this time.

REACTIONS OF BOILER MANUFACTURERS

Representatives of each of the four boiler manufacturers with equipment in the Union Electric Company system were queried as to the feasibility of firing small percentages of prepared refuse to their respective boilers. Reactions were varied, but generally favorable, with the greatest concern

being voiced as to the degree of preparation of the refuse and the amount of unburned material which might fall into the bottom ash hopper.

Combustion Engineering, Inc., have provided data and opinions relating to their equipment and to the evaluation of potentially adverse conditions resulting from the firing of refuse. Their conclusion is that the performance of their tangentially fired units would be virtually unchanged and that no significant change in corrosion, erosion, slagging or general operating procedures would be expected, but that test probes should be installed at various locations in the boiler to evaluate such effects should a tangentially-fired boiler be used as a prototype. Some increase in the total ash generated would be expected. Modifications to the burner arrangements would be relatively minor.

The Foster Wheeler Corporation indicated an interest in pursuing the possibilities of the process. Their concerns include the combustible content of the material which would fall into the ash pit, the adequacy of dust collection devices, the degree of fouling of fireside tube surfaces and the influence on combustion of the main fuel and on primary and reheat steam temperatures and control ranges. When queried as to the method of firing applicable to Meramec Unit No. 4, they suggested that the supplementary fuel (prepared refuse) might be applied either by means of a pipe through the center barrel of each of the six upper burners, or by installing new burner ports above the top row of existing burners, which would require some modification to the water wall.

A representative of the Riley Stoker Corporation indicated the opinion that the process was feasible and that their front-fired units could possibly be modified to fire refuse from the sides through new burner ports. Concern was expressed regarding material falling to the bottom ash hopper, with the suggestion that simple grates be installed in the bottom to permit more complete combustion of such material.

A representative of the Babcock and Wilcox Company indicated little interest in applying the process to the cyclone-fired boilers at the Sioux Plant.

BOILER MOST APPLICABLE AS A PROTOTYPE

The power-generating facilities of the Union Electric Company are regarded as being representative of those utilities burning pulverized coal in suspension. As long as large-scale boilers are equipped with bottom ash hoppers and dust eliminators for flue gases, the boilers should have the potential capability of being adaptable to burn prepared refuse as supplementary fuel, even if they presently were burning gas or oil. There are many boilers similar to that of Meramec Unit No. 1, and its components and characteristics are considered representative of a large segment of comparable facilities throughout the United States.

It is concluded that the evaluation of firing controlled percentages of prepared refuse with pulverized coal presently should be confined to Meramec Unit No. 1, at least for purposes of study. The following discussion summarizes those existing features of Meramec Unit No. 1 which are believed to have bearing upon the application of the proposed process. Figure No. 2 shows a section through Meramec Unit No. 1.

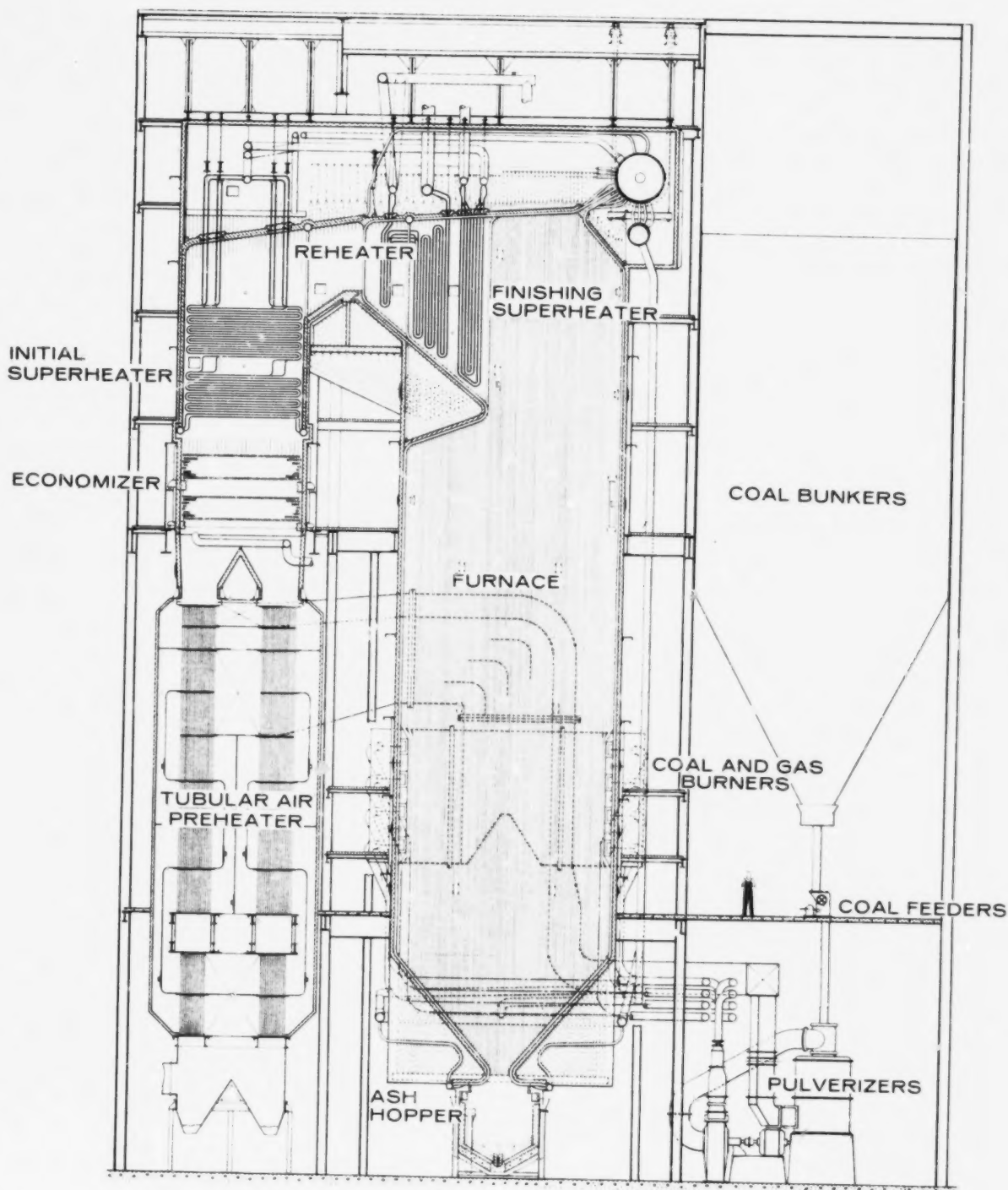
The boiler furnace of Meramec Unit No. 1, built by Combustion Engineering, Inc., is a pulverized coal or natural gas fired unit of the reheat type, with radiant-type water walls. The maximum continuous steam-generating capacity of the unit is 925,000 pounds per hour delivered at the superheater outlet at a pressure of 1,400 psig and a temperature of 950 degrees F. The maximum working steam pressure in the boiler drums is 1,450 psig, and the design pressure of the boiler is 1,500 psig.

Furnace. The furnace is of the water-wall type, with inside dimensions of about 28 feet by 38 feet, and is completely surrounded by 3-inch diameter tubes spaced on 3-1/8-inch centers. The approximate total heating surface is 44,470 square feet. The approximate furnace volume is 96,000 cubic feet. The insulation on the side walls consists of 2-5/8-inch thick castable refractory on the outside of the tubes, reinforced with expanded metal. This is covered with one-inch thick high temperature block, and 1-1/2-inch thick low temperature block, with 5/8-inch thick insulating cement. A 12-gauge welded steel plate casing covers the entire exterior surface of the furnace.

Economizer. The economizer is of the non-steaming, fin tube, separately set type. The gas flow is down through the economizer, and the water flow is up through the tubes. The tubes are arranged in horizontal rows, with the tubes in each row being staggered in relation to those in the row above or below.

Superheater. The superheater is a two-stage convection-type unit with inlet and outlet headers, tube elements and superheater outlet temperature control equipment. The superheater is designed to raise the temperature of the steam to 950 degrees F. (plus or minus 10 degrees F.) at a pressure of 1,400 psig at the superheater outlet and at an evaporation of 60 per cent of the maximum continuous rating. The superheater has a heating surface of approximately 42,600 square feet. A uniform steam temperature of 950 degrees F. is maintained automatically from 50 to 100 per cent of the maximum continuous evaporation by use of desuperheaters.

Two spray-type desuperheaters are located between the initial outlet header and the finishing inlet header of the superheater. Steam from each end of the initial outlet header flows horizontally through the desuperheater adjoining it. A steam-assisted water spray nozzle is fitted in the entering end of each desuperheater to make it possible to reduce the steam temperature, if necessary, before passing on to the finishing stage of the superheater. By this means the steam leaving the finishing stage may be held down to 950 degrees F. within the limits of the capacity of the nozzle.



Sectional Side Arrangement of
C-E Steam Generating Units at
UNION ELECTRIC COMPANY OF MISSOURI, ST. LOUIS, MO.
MERAMEC POWER STATION UNITS NO. 1 AND 2

Although the primary method of superheat control is by means of the desuperheaters, the superheat indirectly tends to respond to burner tilt. Burner tilting controls are controlled by reheater outlet temperatures.

Reheater The reheater is of the convection type with inlet and outlet headers, tube elements and reheater outlet temperature control equipment. It is located between the stages of the superheater. By use of the adjustable burners and the desuperheater, the reheat steam temperature can be maintained at essentially 925 degrees F. at 50 per cent of maximum continuous evaporation. The primary method of controlling the steam temperature is by means of the adjustable burners. The approximate heating surface of the reheater is 10,750 square feet. Two reheater desuperheaters are installed in the lines from the high pressure turbine exhaust and the reheater. A mechanical atomizing water spray nozzle is located downstream from the steam inlet in the side of the desuperheater.

Coal Pulverizers Meramec Unit No. 1 is equipped with four bowl type coal pulverizers to provide a maximum combined quantity of 133,400 pounds of pulverized "lowest grade" (10,000 Btu per pound) coal per hour at the burners. The capacity of each pulverizer is 41,500 pounds per hour, this capacity being such that with one unit out of service the other units are capable of supplying sufficient pulverized coal to permit generation of at least 85 per cent of the specified maximum steam output using the "lowest grade" coal with maximum surface moisture of 12.5 per cent. Each pulverizer is equipped with an exhauster, which, in combination with the coal, will supply 64,200 pounds per hour of primary air at 170 degrees F. when discharging against a pressure of 1.0 inch of water at the burners and when supplied with preheated air at 628 degrees F. entering the mill at zero inches of water. The exhauster is directly connected to the mill drive shaft. It is a straight blade, single bearing, overhung wheel type fan with renewable blades. The scroll is provided with renewable liners.

The coal fed to the mills falls to the center of the revolving bowl, where it is thrown by centrifugal force between the grinding ring in the revolving ring and the rolls. The spring pressure on the rolls provides the pressure for grinding. The air enters through the air housing, over the top of the revolving bowl, and the fines are picked up by the air and carried through the deflector openings into the adjustable classifier which returns oversize particles to the bowl for regrinding. The rising current of air around the bowl tends to keep the coarse material in the bowl until it is pulverized sufficiently.

Any tramp iron or foreign material in the coal fed to the pulverizer is carried over the top of the bowl where it drops out through the air stream onto the lower part of the housing. Pivoted scrapers attached to the bowl sweep this material out of the tramp iron discharge spout. The pulverized coal is carried out of the classifier by suction from the exhauster through piping. A damper is provided for regulation of the air and coal mixture.

Coal Feeders. Each pulverizer is equipped with a Raymond rotary-type automatic coal feeder. The feeder design provides an adjustable rate of feed from a minimum of 10,000 pounds per hour of "average grade" coal per hour to the full maximum pulverizer capacity of 41,500 pounds of average grade coal per hour. The arrangement of the mechanism is such that the adjustment from one rate of feed to another can be made either automatically by the combustion control system or by the operator while the machine is running and without shutting off the supply of coal.

Fuel Burning Equipment There are sixteen 12-inch adjustable burners of the combination type located in the corners of the furnace and arranged for tangential firing. The burners are provided with air-mixing chambers, adjustable air dampers and connections to receive burner piping. Also furnished for the burners are natural gas nozzles with sufficient capacity to permit the boiler unit to operate at full load. An automatic electrical ignition system is arranged for natural gas firing complete with transformers, gas pilots and other accessories. The system is designed to permit future operation with light oil.

Leeds and Northrup drive units are furnished for changing burner tilt. One drive unit is located at each corner group of burners. These drive units are actuated by the reheater outlet steam temperature controller to either elevate or depress the coal and air nozzles, and thereby regulate the temperature of the gas entering the reheater. In addition, an air flow controller is utilized to anticipate steam temperature changes by change of gas mass flow to the superheater, and the temperature detection lag thereby is reduced. All drive units will assume the same angular elevation by means of equalizing relays connected between them.

Temperature recording and controlling instruments, transfer switches and position indicators are located in the control room. The transfer switches permit immediate transfer from automatic to manual control or from manual to automatic control. The position indicator provides the boiler operator with information on burner elevation.

Each of the four levels of coal burners is supplied by one pulverizer.

There are six load gas burners in each corner of the furnace. These load gas burners are arranged in groups of two in each corner. The lower group of gas burners are located between the lowest and the next lowest coal burners; the middle gas burners between the middle two coal burners, and the upper gas burners between the top and the next to the top coal burners. The warm-up gas burner in each corner is located between the two lower load gas burners. A pilot gas torch is located opposite each coal burner and also opposite the warm-up gas burner.

In each corner a set of secondary air dampers is provided for each coal burner and for each of the three levels of load gas burners. Secondary air

dampers also are provided for the aperture below the lowest coal burner and for the aperture above the top coal burner, for a total of nine levels of secondary air dampers per corner.

Ignition System. There are five pilot gas torches at each corner. One is adjacent to each of the coal nozzles, and the fifth is opposite the warm-up torch. The pilot gas torch is a spark-ignited gas burner which has a small shielded pilot flame to prevent its being snuffed out.

Air Preheater. A tubular air preheater is provided with gas flow down through the tubes and air flow over the tubes. The total heating surface is 269,600 square feet, with two primary air passes and four secondary air passes. The air heater equipment has sufficient capacity to heat the required quantities of air from an air inlet temperature of 80 degrees F. to the outlet temperature required at the particular loads. Steam coil air preheaters are provided to preheat the incoming air that goes to the tubular air preheater.

Forced Draft Fans. Two forced draft fans are provided, each capable of delivering 150,000 cfm of air at 100 degrees F.

Induced Draft Fans. The unit is equipped with two induced draft fans, each capable of delivering 235,000 cfm at 277 degrees F. and 17.1 inches of water.

Flue Dust Eliminator. The unit is equipped with Research-Cottrell electrostatic precipitators for removing dust from the flue gases.

Furnace Bottom Ash System. A flooded bottom ash hopper is installed under the boiler. It is filled with water which is maintained at the required level by means of an overflow pipe which drains to a dirty water sump. Around the top of the ash hopper is a seal trough which prevents furnace gases from escaping. The seal trough is kept full of water by a constant flow (200 gpm) of raw water into the trough. Seal plates welded to the bottom of the water wall headers directly above the trough extend into the water to provide the seal. The water flowing into the trough flows out into the ash pit, so that the sides of the ash pit are kept wet.

The ash accumulating in the hopper is removed periodically by sluicing. A system of sluice nozzles in the bottom of the pit is used to sluice the ash out through a hydraulically operated door in the end of the ash pit into a hopper which empties into a pump intake. Before entering the hopper, the ash passes through a hard iron grid which prevents clinkers from getting into the hopper. Larger clinkers are broken up into small pieces with a sledge hammer so that they will pass through the grid.

Sluicing the ash out of the ash hopper is a manually controlled operation. The door at the end of the hopper is operated hydraulically. Hand-operated valves in the individual lines to the sluice nozzles are opened as required by the operator.

The pump which empties the hopper discharges to a slurry tank outside the plant. Three 1,700 gpm rubber-lined ash pumps pump from the slurry tank to the ash fill area.

Precipitator Fly Ash Conveyor. Dust from the precipitator hoppers is handled pneumatically by means of two conveyors which discharge into the same slurry tank receiving ash from the furnace bottom.

Pyrites Conveyor. Rejects from each coal pulverizer are discharged into a hopper located near the base of each mill. They are transported to the furnace bottom ash hopper by means of a high pressure water jet.

Air Heater Ash Conveyor. Fly ash from the air heater hoppers drops to troughs from which it is sluiced periodically into a hopper. From there it is transported by means of a high pressure water jet to the furnace bottom ash hopper.

PART VI

POTENTIAL EFFECTS OF FIRING REFUSE UPON OPERATION OF UTILITY BOILERS

GENERAL

It is mandatory that the reliability of utility boiler facilities will not be adversely affected by the firing of even a small percentage of a relatively heterogeneous fuel such as municipal refuse. The great dependence of the industrial, commercial, institutional and domestic segments of metropolitan areas upon electricity production will not permit indiscriminate experimentation with the highly complex and costly facilities used to produce electricity. It is necessary, therefore, that all the potentially adverse effects and conditions resulting from the firing of refuse as fuel in such units be explored thoroughly.

The suspension firing of bark, waste wood and similar materials in boilers is not new, and has been successfully applied in the paper industry for some time. The principles and problems of the suspension firing of such materials are similar in many respects to those to be expected in firing prepared refuse. One industry, the Eastman Kodak Company, has contracted for the construction of a suspension-fired boiler in which the principal fuel will be shredded refuse generated from in-plant sources. It is understood that no fuel preparation other than shredding of the waste materials is to be performed for this application. There is no available comparison between this waste material and normal municipal refuse.

The following discussions reflect two basic limitations imposed upon the process contemplated in this study:

1. That the refuse will be adequately prepared before firing to the boilers; and
2. That the amount of prepared refuse fired will be only a relatively small percentage of the total fuel fired.

It is considered that any potentially adverse effects from firing refuse will be minimized by these two limitations.

The discussions set forth in the following paragraphs are referenced to Meramec Unit No. 1 of the Union Electric Company system. It is believed that the discussions generally apply to most large-scale suspension-fired boilers. Meramec Unit No. 1, designed and built by Combustion Engineering, Incorporated, includes features which are distinctive and proprietary with

the manufacturer. Combustion Engineering, Incorporated, therefore was consulted relating to the technical feasibility of burning prepared refuse as a supplementary fuel in the boiler furnace. Their cooperation is evidenced by their report of investigations conducted by their personnel, which is included herein as an appendix.

PARTICLE SIZE

All existing conventional municipal refuse incinerators in this country burn refuse on grate systems of various types. The use of grates obviates the preparation of the refuse prior to firing in such installations. However, the almost infinite variety of sizes and shapes of the individual components of raw refuse makes it necessary to process raw refuse before it can be fired to boilers equipped to burn pulverized coal. Firing of municipal refuse to suspension-fired pulverized coal boilers has not yet been attempted, and the only practical guides as to what particle sizes may prove to be satisfactory are the experiences of industrial applications in the burning of bark and waste wood, along with judgment as to what particle size would be appropriate for the conditions prevailing at those specific boilers being given consideration.

The coal used in boilers fired with pulverized coal in suspension normally is milled so that about 70 per cent of the coal particles will pass a 200 mesh sieve. It is considered impractical to attempt to reduce the particle size of refuse to this degree, and from the experiences obtained in burning waste industrial products, unnecessary. The optimum particle size of prepared refuse should be that which permits reasonably complete combustion of the material within the furnace, with a minimum of unburned material falling to the bottom ash receptacle. It is believed probable that the optimum particle size may be dependent to some degree upon the configuration of the boiler furnace and upon the location and spacing of the burner units.

It has been suggested by one boiler manufacturer that the particle size for prepared refuse could be as large as two inches for suspension firing. Another manufacturer indicated the particle size should be about one-half inch. Considering that the major component of prepared refuse will probably be waste paper, it is considered reasonably conservative to provide for a particle size of about one inch. Combustion Engineering, Incorporated, has indicated concurrence with this approach.

Heavy-duty hammermill type crushers have been used successfully in reducing the size of particles in refuse. The power required by such machines in reducing particle size increases exponentially as the particle size decreases. The particle sizes achieved by hammermills are controlled by the sizes of openings in their discharge grates. The discharge grates usually are arranged so that they can be removed and replaced with grates of different sized openings, thereby providing a relatively convenient means of changing

the particle size, should it appear desirable to do so. This feature may be of value in a full-scale application of the process, since there is no specific prior experience to serve as a guide for processing refuse, and since the optimum particle size probably can be determined only by full scale testing

NON-BURNABLE MATERIALS

The data presented in Tables 2, 3, 4 and 5 include the percentages of non-burnable materials in several samples of refuse. The samples are believed to be reasonably representative of the refuse quality prevailing in the St. Louis area, and the limited investigations described in Part III of this report served to generally confirm this belief. It will be noted that the metallic fraction varied from 7.23 to 10.60 per cent, and that glass and ceramic materials comprised from 7.13 to 11.87 per cent by weight of the total refuse. If such components were removed from the refuse prior to the size reduction process, hand picking would be necessary, a costly procedure because of the amount of labor required. However, after size reduction is effected, the removal of magnetic materials, which comprise the largest component of the metallics in the refuse, can be accomplished readily by means of magnetic separators. It is estimated that 90 to 95 per cent of the magnetic materials can be removed by commercially available magnetic separators.

Glass and ceramic materials will be shattered into small fragments by the impact and abrasion resulting from the violent action within a hammermill. The screening tests described in Part III of this report indicate that most of such glass and ceramic fragments could be removed by screening, if sufficient screen area could be provided. Large scale processing facilities would require multiple screening units, however, because of the large volume of material to be handled, and the processing system would be complicated significantly by the conveying system which must provide for the distribution of the material to be screened, as well as for the collection and handling of the several fractions resulting from screening. Screening also will remove a portion of the more finely divided organic materials which have fuel value. Experiments on a laboratory scale indicated the fraction passing a 6-mesh screen to be on the order of 20 per cent of the milled material, with a fuel value in the range of 2,100 to 4,000 Btu per pound. It would be possible, by the application of specialized equipment, to effect a differential gravity separation of glass and ceramic particles from at least most of the organic materials in the screenings. Whether the additional complexity of processing the milled material to remove the glass and ceramic particles is justified is a matter of conjecture at this stage. If the material were to be permitted to remain in the material fired to boilers, the quantity of bottom ash would be increased to some degree. Whether the slagging characteristics of boilers would be adversely affected can be determined only by full scale testing.

The materials removed from the burnable fraction undoubtedly will contain some portion of putrescible matter. It therefore will probably be necessary to dispose of these materials by sanitary landfill.

VARIATIONS IN HEATING VALUE OF PREPARED REFUSE

Raw refuse is extremely heterogeneous, and its composition will vary from hour to hour, from day to day, and from season to season. Refuse also is known to have changed in composition over a period of years, in that far greater percentages of paper and synthetic materials are in evidence at present than formerly was the case. The garbage fraction of refuse has decreased, as has the quantity of ash from coal-fired household furnaces. The net effect of the long-term changes in refuse composition has been to increase the calorific value of the refuse.

Examination of Table No. 5 will demonstrate that when the mineral and metallic fractions, which have very low calorific values, are substantially removed, the remaining constituents, with the exception of the synthetics, have high heat values in the range of 6,200 to 8,200 Btu per pound, dry basis. The percentage of synthetics in raw municipal refuse normally is low, on the order of 2 to 4 per cent by weight, although it may occasionally be as great as 8 to 10 per cent. Thus, even when the relatively high calorific values in the plastic materials are included, the total average calorific value of prepared refuse, with non-burnables removed, and with the intimate mixing which will be effected by the hammermills and the screening and conveying operations, should be relatively consistent, with the actual fuel value dependent mainly upon the moisture content.

MOISTURE CONTENT

The data presented in Table No. 4 indicate the variability in moisture content which can be expected in the constituents of refuse. The normal amount of moisture in refuse is shown to be between 20 and 30 per cent by weight. However, even though dry weather prevailed when the samples described in Table No. 4 were obtained, one of the samples showed an average weighted moisture content of 42 per cent, apparently because of the presence of grass cuttings. The limited investigations described in Part III of this report generally confirm these findings. There are no known data as to how high the percentage of moisture would rise during rainy periods. It is anticipated that some reduction in the total moisture would be effected in the processing of refuse, because of the heat generation, the violent agitation, and the air circulation within the hammermills, and because of the tumbling action anticipated in screening and conveying.

It is not believed to be advisable to dry the prepared refuse, even by low-temperature drying, at least until more is known about its characteristics in large-scale applications. The potential fire hazard which would exist

through the processing, storage and transport of the prepared refuse would be increased by drying. Further, the additional costs entailed in drying could easily outweigh any potential increase in fuel value. It, of course, is possible that if a refuse processing plant were built in close proximity to a boiler plant, it might be practical to utilize a portion of the flue gas to partially dry the prepared refuse before firing.

From visual inspection of the shredded material as discharged from the mill used for the investigations described in Part III of this report, it was the consensus of those witnessing the shredding operation, including representatives of the Union Electric Company and Combustion Engineering, Incorporated, that the shredded material should burn readily in suspension, under the conditions prevailing in a large utility boiler, although the moisture content of some of the material could have been on the order of 40 per cent.

Considering the imposed limitation that the amount of prepared refuse would be only a relatively small percentage of the fuel fired, it is anticipated that a relatively high moisture content may not be of great significance in boiler operation. Coal can be expected to contain as much as 10 to 15 per cent moisture, and under such a condition a larger percentage of moisture in the refuse fraction would increase the total moisture in the fuel only slightly.

The presence of excessive moisture in the refuse will increase the possibility of difficulties from freezing in cold weather. Under normal circumstances such possibilities would appear to be minimal. The prepared refuse particles should have little, if any, surface moisture on them. Any increased moisture content of the prepared refuse should be mainly that absorbed in the paper particles. The prepared refuse also should have good insulating properties, because of the voids between particles. Should freezing prove to be a problem, it should occur only at those surfaces exposed to cold temperatures. Even an effect such as this is regarded as minimal, since it is anticipated that any storage provided for prepared refuse would be for short periods only, probably no more than a matter of hours.

CARRY-OVER OF DUST AND UNBURNED MATERIALS

The deposition of dust on inaccessible heat exchange surfaces in boilers, with a resulting loss in efficiency, is a common problem in boiler plant operation. Soot blowers are not always completely effective in removing such deposits from critical surfaces.

If refuse were prepared as described previously, by controlling particle size, and by removing at least magnetic metals, the remaining fraction fired to a boiler would have a high percentage of combustible material, most of which would be particles of paper. The paper particles, most of the plastic

materials and other lighter combustible components can be expected to ignite and burn relatively quickly at the 2,200 to 2,400 degree F. temperatures usually maintained in the furnaces of large scale boilers.

From all indications, the point of introducing the prepared refuse to the furnace should be near the middle level of burners, to permit the particles to be subjected to the greatest time, temperature and turbulence necessary for complete combustion. It appears unlikely that unburned particles would be carried out over the top of the furnace of a large scale boiler, some 80 to 100 feet above the lower burners. It of course is recognized that some carry-over could occur, since the vertical gas velocity in the furnace may be as great as 20 to 25 feet per second.

Conventional municipal incinerators, in which raw refuse receives no preparation prior to burning, normally maintain temperatures no greater than 1,800 degrees F. It is not uncommon in such installations for objects such as aluminum foil pie plates, and even fairly large pieces of charred but unburned paper, to be carried out of the combustion chamber by the flue gas. Controlled sizing of the refuse should have the effect of minimizing carry-over, since the smaller particles would have far more surfaces exposed to burning, and there would be no large particles with the aerodynamic properties necessary for them to be carried through the high temperature zones without burning.

SLAGGING EFFECTS

When burning pulverized coal, the interior surfaces of boiler furnaces usually become coated with a film of molten slag. This coating tends to permit some unburned coal particles to stick to it and the coal particles continue to burn on the surfaces. It is anticipated that this same phenomenon will occur to some degree with particles of prepared refuse. At present, when the slag build-up becomes too great, the furnace is allowed to cool to a point at which the differential thermal expansion between the boiler walls and the slag causes the slag to loosen and to drop off.

It is not known whether the slagging tendency would be affected by the firing of small percentages of prepared refuse with the coal. The removal of most of the metallic materials from the refuse should provide a relatively clean fuel. Some of the clays used as binders for certain paper products may be conducive to the formation of slags. It is believed that slagging tendencies may be evaluated fully only by full scale testing.

EFFECTS ON BOTTOM ASH HANDLING

It appears probable that certain types of particles in prepared refuse would drop directly into the ash hopper of a suspension-fired boiler. It is not deemed practical to effect size reduction of refuse particles to a degree

which would even approach the particle sizes achieved in coal pulverizers. There consequently may be the reasonable expectation that particles of wood, heavy cardboard, pieces of citrus rinds and other materials which normally would be combustible, would probably fall to the ash hopper without being completely burned. There also will be a certain amount of metal particles and glass and other non-combustible materials which will not be removed in the preparation process, and which also may be expected to drop into the ash hopper. As pointed out previously, the principal constituent of prepared refuse will be paper, which can be expected to be burned to ash. The proportion of the prepared refuse which would fall to the ash hopper is not known. It is estimated that in the suspension firing of pulverized coal, about 85 per cent of the ash normally is carried out of the furnace with the flue gas with about 15 per cent falling to the ash hopper. Even should a substantially larger percentage of the prepared refuse fall to the bottom, it still may not be of great significance, since the prepared refuse is intended to be only a fraction of the total fuel fired.

The configuration of the bottom of the boiler furnace probably would have some effect upon the quantity of unburned material reaching the ash hopper. Many boilers are constructed with a relatively restricted opening between the furnace and the ash hopper, as shown on Figure No. 2. Since the water walls extend down to the restricted opening, it appears probable that some of the partially burned combustible particles of refuse would adhere to sticky surfaces on the lower furnace walls and continue to burn while adhering to these surfaces. This effect may be enhanced to some degree by the entrance velocity of the particles being blown into the furnace, which is expected to be on the order of 30 feet per second at the point of entry.

Most, but not all, of the suspension-fired boilers used for burning bark in the paper industry are equipped with small grates in the bottom. These grates serve to catch those particles of bark which are not completely burned in suspension and to provide a bed upon which combustion of these particles can be completed. The installation of a similar grate in the bottom of an existing large scale boiler is not considered to be acceptable to the Union Electric Company.

It is not known whether increased problems would occur in handling bottom ash from an existing boiler from the addition of particles of inert or unburned materials from prepared refuse. It is anticipated that any such problems would not be insurmountable, and could be thoroughly evaluated only by a full scale test. Should an initial test indicate that there would be an unacceptable percentage of the prepared refuse falling to the bottom ash hopper without being burned, it might be possible to effect at least partially corrective measures. Such measures might include relocation of the burner nozzles to a higher level, or modifying the nozzles to cause the particles to discharge upward at a slight angle. Either of such measures should increase the time to which the particles would be exposed to the high furnace temperatures.

EROSION EFFECTS

It is known that there are erosive effects from particulate matter carried by the gas streams in both suspension-fired coal boilers and in conventional refuse incinerators. There is no valid comparison of such effects for the two types of operations. Considering the intention of removing at least the magnetic metals from the prepared refuse, it is believed that erosive effects from the prepared refuse would be little different than when only pulverized coal is fired. If a full scale test of the suspension firing of prepared refuse were performed, erosive effects should be among those matters receiving scrutiny during the test.

CORROSION EFFECTS

Knowledge of the causes and of the means of prevention of corrosion in coal-fired utility boilers is far from complete. Extensive research has been done and is continuing relating to the complex corrosion mechanisms and reactions under both high temperature and low temperature conditions. For purposes of this study, it therefore is considered appropriate to confine this discussion to those components of domestic refuse which may evolve corrosive compounds when burned, and to their possible effects upon boilers.

All coal contains some sulfur, and the typical analyses furnished by the Union Electric Company indicate that sulfur may be present in quantities approaching 4 per cent of the as-received weight of coal. When sulfur is burned, oxides of sulfur are formed, which will produce corrosive compounds when combined with other substances present in boiler flue gases. Municipal refuse normally contains a very small percentage of sulfur, on the order of from 0.1 to 0.2 per cent. Thus, if prepared refuse were to replace part of the coal fired to a boiler, the total sulfur in the fuel should decrease, with a possible beneficial effect on the corrosive conditions present within the boiler.

There are no known specific data available relating to the quantities or the chemical composition of chlorine compounds present in municipal refuse other than those developed from the limited investigations described in Part III of this report. These limited investigations showed the chlorine content of the three composite samples to be 0.13, 0.15 and 0.32 per cent by weight on an as-received basis.

Certain of the plastic materials present in refuse are regarded as being potentially harmful. By reference to Table No. 4, it will be noted that the plastic content of the four samples of refuse described therein varied between 2.45 and 8.82 per cent. In the 10-year period from 1959 through 1968, the total production of plastic materials in the United States has grown from slightly over 5 billion to approximately 16 billion pounds per year. As tabulated in "Modern Plastics" magazine (January 1969), the production and sales of the various types of plastics in 1968 were as follows:

<u>Type</u>	<u>Production</u> (millions of pounds)	<u>Sales</u> (millions of pounds)
Alkyds	656	330
Cellulosics	193	191
Coumarone-Indene and Petroleum Resins	348	375
Epoxies	165	154
Phenolics	1,064	897
Polyesters	600	537
Polyethylene, High Density	1,250	1,200
Polyethylene, Low Density	3,100	3,000
Polypropylene	810	830
Polystyrene and Copolymers	2,780	2,740
Polyvinyl Chloride and Copolymers	2,475	2,408
All Other Vinyls	550	530
Urea and Melamine	684	603
Miscellaneous	1,325	1,320
Total	16,000	15,115

Almost all of the plastics have a relatively high calorific value (see Table No. 5), and will burn readily at the temperatures prevailing in the furnace of a utility boiler. The dominant plastics in domestic refuse can be expected to be polyethylene and polystyrene, which should not produce corrosive products of combustion. The only one of the plastics in major use which will produce a corrosive material when burned is polyvinyl chloride, which will produce hydrochloric acid, and which in 1968 comprised about 16 per cent of the total plastics sold. From the 1968 marketing data published by "Modern Plastics" relating to appliances, furniture, housewares, packaging and toys, only about 15 per cent of the total plastics which may reasonably be expected to be included in domestic refuse would be polyvinyl chloride.

If the percentages of plastics in refuse, as shown in Table No. 4, are regarded as typical, the percentages of polyvinyl chloride in refuse should be in the general range of 0.37 to 1.32 per cent of the total refuse. Each pound of polyvinyl chloride will contain about 0.6 pounds of hydrochloric acid. If only a small percentage of the total fuel fired to a boiler were prepared refuse, the percentage of polyvinyl chloride in the total fuel would be correspondingly less. By reference to Table No. 15, it will be seen that the chlorine content of certain of the coals used in Union Electric Company facilities ranges as high as 0.29 per cent.

There is little known of the compounds present in the flue gases of conventional refuse incinerators. It is known, however, that when wet scrubbers are used to remove particulate matter from incinerator flue gases, the scrubbing water becomes acidic, although incinerator residue normally is alkaline. It is possible that the acidity of the scrubbing water is caused by the absorption of chlorine compounds, carbon dioxide and various organic acids.

With the limited knowledge available, it is impractical to predict whether the use of prepared refuse as a small percentage of the total fuel fired to utility boilers would create conditions having greater corrosive effects than when pulverized coal is fired alone. Examination of available data led to the conclusion that the corrosion potential within boilers may be increased slightly when refuse is burned as supplementary fuel. However, it must be recognized that corrosion problems resulting from burning only pulverized coal already have been experienced in boilers, and whether any increased problems would occur in burning refuse as a supplementary fuel is a matter of conjecture. One opinion has been advanced by a representative of Combustion Engineering, Inc., that if a discernible increase in corrosion were to occur, it would be feasible to include a neutralizing additive in the fuel to effect corrosion control. Although the consensus of the opinions of knowledgeable persons consulted on this matter is that it is doubtful that greater corrosive effects of a discernible magnitude would result from the use of refuse as a supplementary fuel, it would appear that provisions for monitoring corrosion potential and effects should be incorporated in full-scale applications of the process.

COMBUSTION AIR

As described earlier in this report, Meramec Unit No. 1 is equipped with two forced draft fans, each capable of supplying 150,000 cfm of air to the furnace at 100 degrees F. The combustion air is preheated to temperatures as high as 628 degrees F.

The most practical method of firing prepared refuse to a tangentially fired boiler such as Meramec Unit No. 1 is considered to be by pneumatic conveying. There must be sufficient velocity imparted to the particles of refuse to carry them into the high temperature zones of the furnace, thereby creating the opportunity for the particles to ignite and burn. A 6-inch diameter pneumatic pipeline can carry about 60 tons per hour of prepared refuse. The quantity of air required for a 60 ton per hour rate is about 1,250 cfm. If four burners in one furnace were each equipped for firing by this means, the total amount of air supplied to the furnace by pneumatic conveying would be only about 5,000 cfm, or less than 1.7 per cent of the capability of the forced draft fans. Since the air supplied by the pneumatic systems would be only a small percentage of the total combustion air requirement, it is considered unnecessary to preheat the air used for pneumatically firing the refuse.

The blowers for the pneumatic systems would be of the positive displacement type, operating at a constant speed. The quantity of air delivered to the refuse burners therefore also would be constant, no matter what the rate of feed of the prepared refuse.

Combustion Engineering, Incorporated, have concluded that air and gas weights would be very close to the original design conditions when prepared

refuse is fired as about 10 per cent of the fuel to the boiler furnace at full load. Excess air is computed to be 23 per cent under this condition as opposed to 22 per cent under the original boiler design conditions. There appears to be no indication that either the existing forced draft fans or the induced draft fans would not be adequate.

SALE OF FLY ASH

The ash collected by the electrostatic precipitators installed at certain of the suspension fired boilers in the Union Electric Company system is sold to portland cement manufacturers. The ash may be used as either a raw material or as an additive. Should prepared refuse be fired in these boilers, some of the resulting ash certainly will be collected by the precipitators along with the ash resulting from burning pulverized coal.

The Missouri Portland Cement Company of St. Louis, Missouri, utilizes fly ash in the production of portland cement, and was queried as to the effect a percentage of ash from prepared refuse would have on the quality of fly ash presently used. Based upon typical ash analyses of both coal and refuse, the composition of an ash comprised of 80 per cent coal ash and 20 per cent refuse ash was computed. The components considered undesirable in cement are MgO , Na_2O , K_2O and P_2O_5 . Assuming 15 per cent of the fly ash as a raw material for cement, the additional quantities of these compounds are not regarded as significant, as long as the alkalies in the calcareous raw materials are not excessive.

When used as a pozzolan, there is no way of predetermining the effect of the combined ash upon concrete without extensive experimentation. However, there appears to be little reason to believe it would be significantly different from coal ash.

The Missouri Portland Cement Company indicated there should be no serious problems in using a combination of coal ash and refuse ash as either a raw material or as a pozzolan.

INTERFERENCE WITH NORMAL OPERATION

Meramec Unit No. 1 presently may be fired with either pulverized coal or gas. As discussed later in this report, Combustion Engineering, Incorporated, recommends the installation of a refuse firing nozzle, between the two middle pulverized coal burners, in each corner of Meramec Unit No. 1. This installation would require removal of the gas burners presently occupying these spaces. The unit therefore could continue to operate at full load on pulverized coal if the refuse feeding system were shut down. The elimination of one level of gas burners would still leave 83 per cent of the existing gas burners available for full load firing. An increase of about 3 psi in gas pressure would supply enough gas for full load. Since it is anticipated

that the prepared refuse would be fired by separate pneumatic systems, and at a constant rate, there should be no interference with the coal pulverizers or other existing firing equipment.

It is anticipated that variations of fuel requirements of the boiler furnace could be accommodated by the existing combustion controls. Thus, at a given boiler load, with the supplementary fuel fired at a constant rate, the existing combustion controls could vary the rate of firing of the pulverized coal, at least within the limits presently provided. Should it appear desirable to change the rate of feed of the refuse, it is considered that the change would be made by manual control, since such a modification should not be required frequently.

It is anticipated that if the process were applied at Meramec Unit No. 1, deliveries of prepared refuse would be made outside the plant limits, with the material conveyed pneumatically to a short-term storage silo inside the plant. The only equipment inside the plant, in addition to the storage silo, would be the feeding equipment and piping. Even if this equipment were installed inside the building, in the vacant bay between Units No. 1 and No. 2, there would be little physical interference with normal plant operations.

AIR POLLUTION CONTROL

The boilers considered most suitable for burning prepared refuse in suspension are equipped with electrostatic precipitators. The substitution of prepared refuse for a small percentage of pulverized coal may result in an increase in the dust loading, but is not expected to result in a discernible difference in the function of the precipitators, nor in the general quality of the dust collected by them. Particulate emissions from the chimneys should not necessarily be increased by application of the proposed process.

The sulfur content of refuse is small, far less than the sulfur present in even high grade coal. (See Tables No. 14 and 15) It is considered probable that some decrease in the emission of sulfur oxides would result from the substitution of prepared refuse for part of the coal normally fired. One of the existing Union Electric Company boilers has been equipped with facilities (the alkaline earth process) to remove sulfur oxides from the flue gas. The firing of a small percentage of prepared refuse with coal is not considered adverse to the function of such sulfur oxide removal equipment.

The air pollution control regulations in effect in the St. Louis area require the use of low sulfur coal (approximately 1.4 per cent maximum sulfur) by March 24, 1970. The use of low sulfur coal undoubtedly will increase utility fuel costs, and it is possible that the use of prepared refuse as supplementary fuel also could assist in minimizing such fuel cost increases.

There presently are no standards relating to the control of nitrogen oxides from power plants, although air quality objectives include limits on nitrogen oxides in ambient air. There is some controversy as to whether objectionable quantities, if any, of such oxides are formed in boiler furnaces. There appears to be no reason to believe that the formation of nitrogen compounds would be increased significantly by the burning of prepared refuse as a supplementary fuel.

PART VII

FACILITIES REQUIRED FOR APPLICATION OF PROCESS

GENERAL

All of the major power plants in the St. Louis area, as well as in many other parts of the country, which are considered adaptable for burning prepared refuse as supplementary fuel, are located some distance from the centers of refuse production. It is necessary, therefore, to consider that many of the potential applications of the process would require facilities comprised of three basic elements:

1. Preparation facilities, located for practical reasons near a center of refuse production.
2. Transport facilities, to transport the prepared refuse from the preparation plant to the power plant.
3. Boiler plant facilities, to receive the prepared refuse at the plant, to store sufficient material to assure continuity of a supplementary fuel supply, and to fire the material to the boiler furnaces at an acceptable rate.

Matters requiring resolution in applying the proposed process include:

1. Determination of the capability of the available boiler plants to burn refuse as a supplementary fuel.
2. Determination of the quantity of refuse available as fuel.
3. Resolution of the differences of scheduling of refuse collection with boiler operation.
4. Determination of the potential rate of processing refuse.
5. Determination of the most appropriate capacities and layout of preparation and storage facilities.
6. Consideration of the relative location of a processing plant to a boiler plant.
7. Determination of the most desirable type of preparation facilities.
8. Consideration of the various methods available for transporting prepared refuse to the boiler plant.
9. Determination of the facilities required at the boiler plant for receiving, storing and firing the prepared refuse to boilers.

CAPABILITY OF BOILERS TO BURN PREPARED REFUSE

Three of the Union Electric Company plants appear to have the greatest potential for adaptation for the burning of prepared refuse as a supplementary fuel. These three plants include Venice Plant No. 2, the Meramec Plant and the Labadie Plant, which presently is under construction. The Ashley Street Plant and the Sioux Plant are not considered as applicable as the other three at this time.

Table No. 17 lists pertinent data relative to the quantities of prepared refuse which might be fired to the individual units of each of the three plants considered to have the greatest potential. This table also develops the approximate values of the prepared refuse as fuel if fired to each unit of each plant, assuming that 10 per cent of the fuel value of the coal were replaced by prepared refuse, and also assuming that the presently prevailing approximate use factors of the units would apply. It should be recognized that if it were found feasible to replace more than 10 per cent of the fuel value of coal with refuse, the quantities of refuse which could be burned, as well as their corresponding values as fuel, would increase. Similarly, if the quantities of refuse fired were less than 10 per cent, the contrary would be the case.

The use factor of a power-generating unit may be generally defined as the quantity of power generated during a given period of time (usually one year), divided by the power-generating capability of the unit during the same period. Large power-generating units are seldom operated consistently at a level below 50 per cent of their capability, and the less efficient units of a given power system may actually be deactivated during those periods when the demand for electricity is least. The level of operation resulting in the most favorable economic pattern normally is at a loading on the order of 90 per cent of the unit's capability.

It may be noted that the low values shown for Venice Plant No. 2 in Table No. 17 are due principally to the low use factors. If it were found attractive to the Union Electric Company to use prepared refuse as a supplementary fuel, the present use factors possibly would increase substantially. However, the boilers at the Venice Plant are smaller than those at either the Meramec or the Labadie plants, and would require more complex installations at the plant to handle the supplementary fuel and to fire it to the boiler furnaces. It also should be recognized that a reduction in fuel cost of about 20 per cent would be required to make the Venice boilers attractive as base load units.

For the Meramec Plant only, under the assumptions presented in Table No. 17, and if all four units were modified to burn a percentage of refuse with coal, at their present use factors the maximum total quantity of prepared material which could be consumed as supplementary fuel would be on the order of 363,000 tons per year. It appears likely, however, that a

TABLE NO. 17

POTENTIAL CAPACITY FOR BURNING REFUSE
UNION ELECTRIC COMPANY PLANTS

	Coal Burned at Full Load tons/hr	Coal Heating Value Btu/lb	Refuse (b) Equivalent to 10% of Coal tons/hr	Present Use Factor %	Prepared Refuse Potential tons/yr	Equivalent (d) Raw Refuse tons/yr	Approx. 1970 Cost of Coal \$/ton	Approx. Fuel Value of Refuse Fired \$/yr
VENICE PLANT NO. 2								
Unit No. 1	26.0	10,500	5.5	20	6,800	7,600	\$5.02	\$ 16,300
Unit No. 2	26.0	10,500	5.5	20	6,800	7,600	5.02	16,300
Unit No. 3	26.0	10,500	5.5	20	6,800	7,600	5.02	16,300
Unit No. 4	26.0	10,500	5.5	20	6,800	7,600	5.02	16,300
Unit No. 5	26.0	10,500	5.5	20	6,800	7,600	5.02	16,300
Unit No. 6	26.0	10,500	5.5	20	6,800	7,600	5.02	16,300
Unit No. 7	53.0	10,700	11.1	20	13,800	15,400	5.11	33,000
Unit No. 8	53.0	10,700	11.1	20	13,800	15,400	5.11	33,000
MERAMEC PLANT								
Unit No. 1	57.5	10,500	12.1	70	52,800	58,700	5.10	\$128,000
Unit No. 2	57.5	10,500	12.1	70	52,800	58,700	5.10	128,000
Unit No. 3	116.0	10,650	24.7	75	115,500	128,500	5.20	282,000
Unit No. 4	143.0	10,650	30.4	75	142,300	158,000	5.20	348,000
LABADIE PLANT (a)								
Unit No. 1	238.0	11,500	54.8	90	306,000	342,000	5.18	\$695,000
Unit No. 2	238.0	11,500	54.8	90	308,000	342,000	5.18	695,000
Unit No. 3	238.0	11,500	54.8	90	308,000	342,000	5.18	695,000
Unit No. 4	238.0	11,500	54.8	90	308,000	342,000	5.18	695,000

(a) Labadie Plant under construction.

(b) Refuse assumed at 5,000 Btu/lb.

(c) At assumed present use factor, with refuse fired only 5 days/wk.

(d) Assuming magnetic metal removed.

boiler using refuse as supplementary fuel would be operated essentially as a base-loaded unit, in order to take maximum advantage of the potential economy in fuel cost, with the result that the applicable use factors might well be on the order of 90 per cent. All four of the boilers at the Meramec Plant cannot be expected to be operating at all times, and it therefore is appropriate to consider that only three of the four units would be available to burn prepared refuse at a given time. Taking these premises into account, the potential capability of the four units at the Meramec Plant may be considered to be as follows:

Boiler Unit	Refuse Equivalent to 10% Coal tons/hr	Assumed Use Factor - %	Prepared Refuse Potential tons/yr (a)	Equivalent Raw Refuse tons/yr (b)
Unit No. 1	12.1	90	68,000	75,500
Unit No. 2	12.1	90	68,000	75,500
Unit No. 3	24.7	90	138,700	154,000
Unit No. 4	30.4	90	170,700	190,000

(a) Assuming refuse fired 5 days per week

(b) Assuming only magnetic metals removed.

Considering only the three smallest of the boilers at the Meramec Plant to be burning refuse as supplementary fuel at one time, the total quantity which would be fired in one year would be about 274,700 tons, which would be equivalent to about 305,000 tons of raw refuse per year, almost 1.4 times the quantity presently collected by City of St. Louis vehicles. This capability would increase to about 366,000 tons of raw refuse per year if the material were burned 6 days per week.

Each of the four units under construction at the Labadie Plant, under the assumptions presented in Table No. 17, could consume about 308,000 tons per year of prepared refuse, which would be equivalent to about 342,000 tons of raw refuse per year. If only three of these four units were to burn refuse as a supplementary fuel at one time, their combined nominal capability would be on the order of 924,000 tons of prepared refuse per year, which would be the equivalent of about 63 per cent of all the refuse presently produced within the entire St. Louis metropolitan area. Again, this capability would increase to about 1,230,000 tons of raw refuse per year if the material were burned 6 days per week.

It may be reasonably concluded that the boiler facilities of the Union Electric Company have the potential capability of consuming essentially all of the burnable refuse which is produced within the St. Louis metropolitan area. This capability is on the increase, since the production of electricity is increasing at the rate of about 7 per cent per year, a greater rate of increase than that of the production of refuse, and since at least one additional major coal-fired boiler plant is planned for the St. Louis area.

QUANTITY OF REFUSE AVAILABLE AS FUEL

It was pointed out in Part II of this report that the 2,500,000 population of the St. Louis metropolitan area produces an estimated average of 4,000 tons of mixed municipal refuse per day, of which about 3,000 tons per day is generated in Missouri. Under the prevailing conditions, only a portion of this total quantity can realistically be considered to be available as a potential source of supplementary fuel. It is doubtful that any of the refuse produced in the Illinois portion of the metropolitan area (presently about 1,000 tons per day) would be available because of the relatively low disposal costs prevailing in the Illinois communities at this time. Between 1,100 and 1,500 tons per day of refuse from Missouri presently are disposed of in Illinois landfills. If large scale processing facilities were conveniently located for the haulers, particularly for the private haulers, and if the disposal fees charged at the processing plant were not excessive, a portion of the 1,000 to 1,500 tons per day presently hauled to Illinois probably would become available as a source of supplementary fuel. It also is considered probable, assuming an attractive economic pattern, that all of the 800 to 1,000 tons of refuse per day collected by the City of St. Louis vehicles would be available for processing. At the present time it is estimated that possibly half of the remaining refuse produced locally, most of which would originate in St. Louis County, could also be considered available as a source of supplementary fuel.

In summary, it is believed that an average of about 2,000 tons of refuse per day, under the presently prevailing conditions, would be available for processing as supplementary fuel, as long as a favorable economic situation prevails. It appears probable that this quantity could increase in the near future, as the existing landfill sites in St. Louis County are exhausted, and should the Illinois authorities wish to make it less attractive for Missouri haulers to dispose of refuse in Illinois. For the present, however, for purposes of this report, an average potential quantity of 2,000 tons per day, with a peak quantity of about 2,500 tons per day, and a minimum quantity of about 1,500 tons per day, appears realistic as a source of supplementary boiler fuel.

SCHEDULING OF REFUSE COLLECTION VERSUS BOILER OPERATION

A base-loaded utility boiler normally is expected to operate continuously, near full load, on a 24-hour day, 7-day per week basis for a year or more without a major interruption for repairs or maintenance. Except in the event of an emergency, shutdowns of such facilities are scheduled far in advance, to ensure that other facilities will be available to accommodate the required power generation load during the shutdowns.

Municipal refuse, although produced seven days per week, normally is collected only five or six days per week, and only during the daylight hours.

It is considered impractical, as well as unacceptable to the general public, to collect refuse, particularly domestic refuse, on other than an 8-hour day, five or six day per week schedule.

The difference between the scheduling of a utility's operation and that of municipal refuse collection obviously must be reconciled to permit full achievement of the potential economic and social benefits accruing from the process. From the utility's standpoint, the most desirable arrangement would provide for the delivery of supplementary fuel at a constant rate, seven days per week, and it would be possible to effect such an arrangement by providing storage facilities for either the raw or prepared refuse of sufficient capacity to accommodate weekend requirements. Since the amount of storage required for this length of time would be excessive, and would result in double handling of the material, a more practical approach would be one in which all of the available burnable material would be consumed during a normal five or six day week by the utility. In this case the number of days during which the supplementary fuel would be processed and burned would be dependent upon collection practices, and the storage and handling problem would be simplified. Under this latter premise, the utility would in effect operate without the supplementary fuel on Sundays, and in some cases on Saturdays, when the demand for electricity normally would be at a minimum. Recognizing that the capability of large-scale boiler furnaces often will exceed the quantity of refuse available as supplementary fuel, it would appear appropriate to schedule both the preparation and the burning of the refuse only for the normal refuse collection days, and such an arrangement is assumed for purposes of this report.

POTENTIAL RATE OF PROCESSING

The potentially great capability of major utility boilers to consume prepared refuse as supplementary fuel, and the large quantities of mixed municipal refuse available as supplementary fuel in metropolitan areas, lead to the conclusion that the proposed process should be applied on the largest reasonable scale. The three smallest boiler units at the Union Electric Company's Meramec plant have the potential capability of burning 274,700 tons of prepared refuse per year, and any one of the four units at the Labadie Plant could burn about 308,000 tons per year, based on the assumptions that refuse would replace about 10 per cent of the fuel value of pulverized coal, and that the boilers would be operated at a use factor of 90 per cent. If the supplementary fuel were fired at a constant rate, 24 hours per day and 5 days per week, the total possible firing rate for the three smallest boilers at Meramec, plus one boiler at Labadie, under these assumptions would be 93 tons of prepared refuse per hour, which would be approximately equivalent to an average of 100 tons of raw refuse per hour over a 24-hour day. If disposal of refuse at this rate is assured by the proposed process, the processing facilities could be built to have any reasonable capability at least up to this limit.

One of the principal limitations of the process contemplated for preparing refuse for firing to boiler furnaces is the relatively high maintenance required for the hammermills normally utilized to effect particle size reduction. It is anticipated that the wear of the hammers in these mills will be such that the hammers will require retipping after possibly 40 hours or less of operation. It is necessary, therefore, to provide time in the processing schedule to permit the necessary maintenance without interference with the required production rate. For this reason it is believed to be inadvisable to schedule the operation of such mills for more than two 8-hour working shifts per 24-hour day. Further, operating schedules should permit time during the working shifts for preventive maintenance of other equipment and for housekeeping functions, so that the total available operating time in two working shifts would be only 14 to 15 hours.

NOMINAL CAPACITY AND LAYOUT OF PROCESSING UNIT

The largest hammermill installation known to be operating in the United States on a consistent basis at this time, for the milling of mixed municipal refuse, is at a composting plant in Houston, Texas. The primary mill in this case is understood to have a nominal capacity of about 40 tons of raw refuse per hour, with the capability of handling surges of up to about 50 tons per hour. It is understood the system operates 8 to 10 hours per day, depending upon the quantity of refuse delivered to the plant. Observations of this operation, together with discussions with hammermill manufacturers, have resulted in the conclusion that with proper design of the feeding and discharge conveying systems, a hammermill installation of approximately 70 tons per hour average capacity would be feasible. It is understood that hammermills capable of processing as much as 100 tons per hour of raw refuse are in operation in Europe.

If a hammermill system of smaller size were used, such as one having a nominal capacity of 40 tons per hour, multiple units would be required to achieve the same capacity as that of larger units. This would provide greater operational flexibility. However, if the processing were confined to a normal schedule of no more than two shifts per day, with the third shift available for hammer retipping or major repairs, and if an effective preventive maintenance program were practiced, it would appear that the installation of the smaller units merely to provide additional operational flexibility would be difficult to justify, because of the higher unit production costs to be expected for smaller multiple units.

In view of the large scale on which it appears to be possible to apply the proposed process in metropolitan areas, it is concluded that the nominal average capacity of a single refuse processing unit should be about 70 tons of raw refuse per hour. Even with processing units having this great a capability, two shifts per day, the potentially significant economic benefits to be derived from large-scale operation lead to the further conclusion that more than one processing unit would be justified in most cases, because of the potentially great capability of the boilers adaptable for burning refuse as supplementary fuel.

Considering the heterogeneous nature of raw refuse, and the attendant difficulties to be expected in maintaining a constant rate of flow of raw material, the equipment must be capable of accommodating higher rates of feed during those short periods when surges of the material will be fed to the mill. As a matter of judgment, it is believed that a mill of an average capability of 70 tons per hour should be able to handle momentary surges of up to 100 tons per hour. The conveying systems also must be capable of accommodating such surges.

With an average input of 70 tons of raw refuse per hour, and if only the magnetic metals were removed in processing, the production of prepared refuse would be at the rate of about 65 tons per hour, assuming that magnetic metals comprise an average of 7.5 per cent of the raw refuse. If magnetic metals, together with glass and ceramic particles were removed, the production of prepared refuse would be at the approximate rate of 49 tons per hour, assuming that 30 per cent of the raw material would be removed by magnetic separation and screening.

A single processing unit, for purposes of evaluation, is considered to be comprised of all conveyors, mills, separators and auxiliary equipment required to process raw refuse at a 70-ton per hour rate. The capability of a single processing unit of the size contemplated therefore would be about 490 tons of raw refuse per day in a 7-hour working shift, or about 980 tons per day in an operating period of 14 hours over two shifts.

RAW REFUSE STORAGE

An important factor in determining an appropriate processing layout is the schedule of deliveries of raw refuse to the processing plant by the collection trucks, and the effect of such a schedule upon the logistics of raw refuse handling. Essentially all of the refuse collected by City of St. Louis vehicles is delivered to the City Incinerators within a 6-hour period, on only five days per week. In the case of private haulers engaged in the collection of refuse in the St. Louis metropolitan area, the deliveries usually are made over a relatively full 8-hour day, and are made six days per week. As previously pointed out, it is not considered practical to attempt to modify the scheduling of refuse collections. Unless the processing facilities were to include provisions for storage of that portion of raw refuse to be processed during the second operating shift, it would be necessary to process the material essentially at the rate it is delivered to the plant, and the time of processing a day's delivery of refuse would have to be confined to one 8-hour shift.

The most attractive mode of processing, from an operating standpoint, would be one in which the storage of raw refuse could be kept to a minimum, since double handling of the material then could be avoided. However, if the practical aspects of a given situation were to indicate double handling

of at least a portion of the refuse to be necessary, consideration then must be given to the possibilities of storage facilities. There are three basic methods which have been used to provide storage for raw refuse:

1. Deep, large-volume pits, into which the collection trucks dump directly. Top-running cranes, equipped with grapples, are used in this case to convey the stored refuse to the processing equipment.
2. Large, flat dumping areas, on which the refuse is dumped by the collection vehicles. Front-end loaders then are used to push the refuse to conveyors or into small hoppers leading to the processing equipment.
3. Live-bottom pits, consisting of wide, slow-moving conveyors with side walls, which for practical purposes must be of relatively small volume, into which the collection vehicles dump, and from which the live bottoms convey the refuse to the processing facilities.

Each of these three methods have advantages and disadvantages. The pit and crane method functions well when the processing equipment can be operated 24 hours per day at relatively small production rates, such as in conventional refuse incinerators. This method requires a large capital investment, together with substantial operation and maintenance costs in both labor and power. In order to maintain larger production rates of 70 tons per hour or more, the cranes would have to be of far greater capacity than those used in conventional incinerators, and would have correspondingly higher capital costs in both equipment and structures. The pit and crane method also would result in the feeding of raw refuse to the processing equipment in slugs, which would make necessary additional facilities for effecting a relatively constant rate of feed to the hammermills.

The front-end loader method requires large floor areas for storage, and although the relative capital and operating costs are low, the method is not regarded as being completely satisfactory from an aesthetic standpoint. The method also requires conscientious housekeeping to keep potential nuisances under control. Special provisions would be required to control the attendant fire hazards.

The live-bottom pit method permits operation with a minimum amount of labor. Its capital costs are less than those of an equivalent pit and crane installation, but are more than for the front-end loader method. Properly designed and operated live-bottom pits would be capable of accommodating relatively high production rates.

It is feasible to combine live-bottom pits with front-end loader operation, if some floor storage can be condoned. This arrangement could keep floor storage to a minimum. Considering processing facilities designed to

operate 14 hours per day, with all of the raw refuse delivered to the plant during an 8-hour period, the floor storage required would be something less than that required for 6 hours of processing, depending upon the volume of storage available in the live-bottom pits themselves.

For purposes of this study, the processing facilities will include live-bottom receiving pits, with sufficient dumping area to afford adequate storage to allow a total daily processing schedule of 14 hours. These provisions will permit operation on either a one-shift or a two-shift basis.

LOCATION OF PROCESSING PLANT RELATIVE TO BOILER PLANT

The most desirable location of a facility to process refuse as supplementary fuel for boilers would be on or adjacent to the boiler plant premises, in order to effect the greatest economy in utilizing the refuse as supplementary fuel. However, many of the newer major power generating plants in which the supplementary fuel could be used to the best advantage are located some distance from the heavily populated parts of metropolitan areas, and therefore from the centers of refuse production. This is the case in the St. Louis area, in which both the Meramec and the Labadie power plants are located some miles from the heavily populated districts. Locating the processing plant adjacent to the power plant in this case would require all of the raw refuse to be delivered to the boiler plant in either collection trucks or in transfer vehicles, a procedure which almost certainly would be more costly than transporting the milled refuse to the boiler plant from a point near the center of refuse production.

It is conceivable, if the processing facilities were in close proximity to a boiler plant, that a portion of the flue gases could be diverted for the purpose of drying the refuse when the moisture content is abnormally high. It is also conceivable that the exhaust system required for the control of dust in the processing operations could be discharged to the combustion air system of the boiler, with some potential advantage. There also is the possibility that the unit power costs of a facility located adjacent to a power plant would be less than if it were located elsewhere, because of the elimination of the assignable power transmission costs. For purposes of this study, however, these possibilities are not regarded as completely applicable, and are given no further consideration.

It appears probable, at least in the St. Louis area, that it would be more advantageous to locate the processing plant near an established refuse disposal facility, such as an existing refuse incinerator or sanitary landfill. This approach would permit minimum disruption of the established refuse collection truck routes and operations. It also would provide an alternate means of disposing of excess raw refuse in case the processing plant operations were interrupted. Further, it would permit disposal of those fractions of refuse not usable as fuel by means of existing equipment and procedures.

For purposes of this report, it is concluded that the refuse processing facilities should be constructed near a long-range refuse disposal facility. It is assumed that the facilities would be within 25 miles of a power plant adaptable for burning refuse as supplementary fuel. It should be borne in mind that a processing plant could be constructed at any strategic point within a metropolitan area, and that the transport of supplementary fuel from almost any such point to an applicable boiler plant could be effected essentially without sacrificing more than the incremental cost of transport.

PROCESSING FACILITIES

It has been pointed out that the nominal maximum size of the particles believed to be suitable for firing in suspension to large-scale boilers is about 1 inch. This assumption is believed to be on the conservative side, but is regarded as appropriate for purposes of evaluation, at least until some operating experience is gained.

Discussions with equipment manufacturers, and inspection of facilities utilizing milling equipment for mixed refuse, lead to the conclusion that the milling of raw refuse should be performed in two stages in order to achieve a nominal one-inch particle size. It of course is possible to achieve this particle size with single-stage milling, but only at a substantial reduction in production capability. It is understood that when the moisture content is high, a typical single-stage mill might be capable of processing only as little as 50 per cent of the material processed by a unit designed for rough milling only. It is considered of primary importance to provide heavy-duty equipment for milling raw refuse. Mills designed for rough milling are equipped with grate bars with large opening at their discharges, which permit the bars to be of heavier cross-section, and of more rugged design. Should actual operating experience show that particle sizes of, say, 2 inches or larger are suitable for firing to boilers, there appears to be some promise that the milling could be performed in a single-stage unit. In the interest of conservatism, two-stage milling is regarded as necessary at this time.

The bulk densities of both raw and milled refuse are relatively low, and will vary somewhat as the material passes through the various stages of the processing plant. The densities also will vary with the moisture content and as changes occur in the percentages of the individual components. It therefore is necessary that the design of the conveying systems handling both the raw and the milled refuse take the low densities into account, as well as the possibility that the densities will vary. There appears to be no doubt that an average production rate of 70 tons per hour for a single production unit, with momentary peaks up to 100 tons per hour, can be achieved with commercially available conveying equipment.

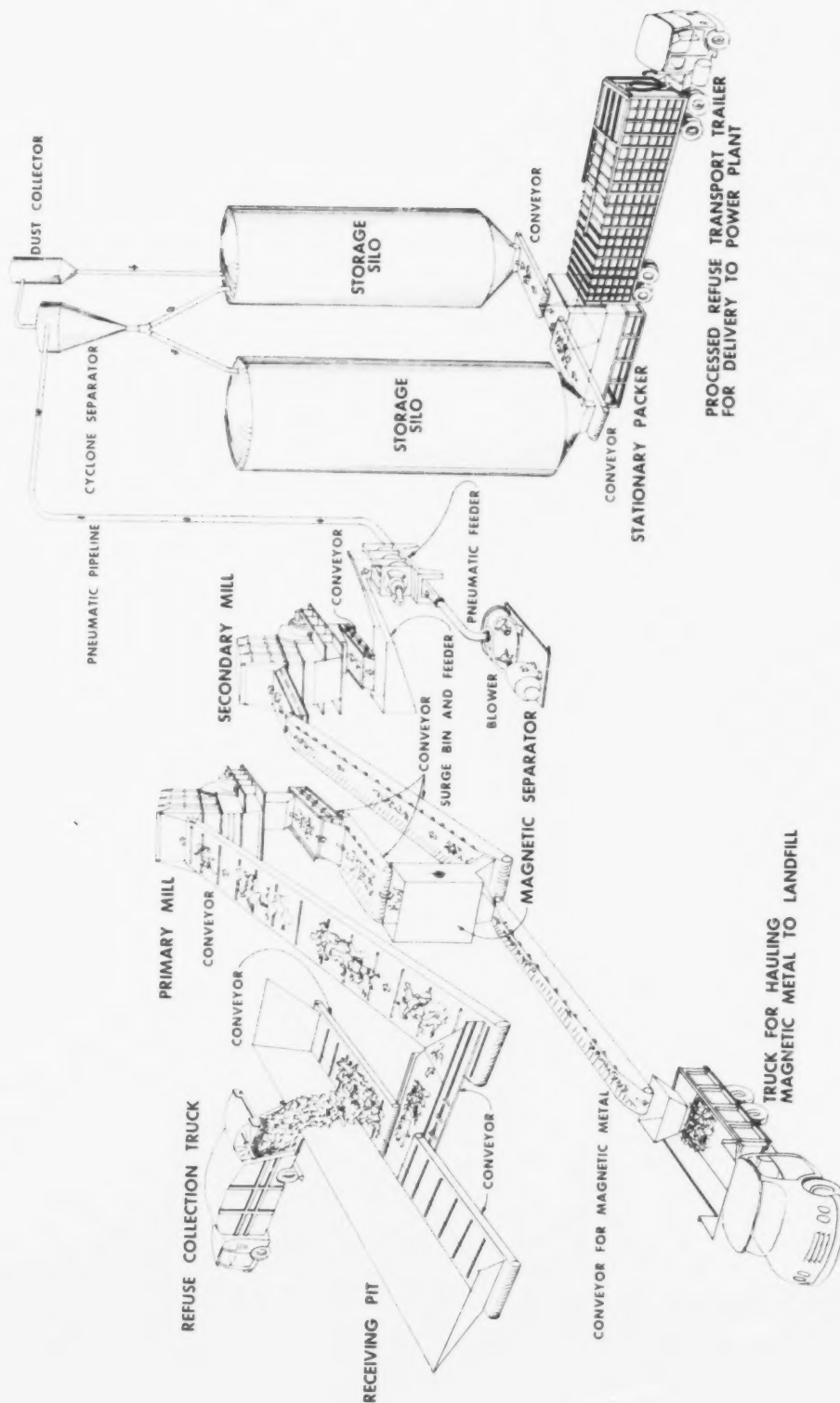
Until operation experience and boiler performance can be assessed, consideration must be given to at least two processing layouts. It is believed

probable that it will be necessary to remove at least the magnetic metal from the raw refuse, and the basic layout described in the following pages so provides. It may be possible that the presence of the milled magnetic metal would not seriously affect the performance of a boiler or its auxiliary equipment, but the magnetic particles may tend to interfere with the operation of pneumatic feeding systems. The conservative approach therefore requires that the magnetic materials be removed. The alternate layouts described hereafter provide for screening facilities to remove particles of glass and ceramic materials. This step may or may not be necessary. It presently is believed probable that boiler performance would not be adversely affected by the presence of such materials.

The materials removed from the milled refuse will require disposal by some means. The magnetic metal will include tinned cans, which detracts from its salvage value. It is assumed that the magnetic metal will not be salvable, and will require disposal by sanitary landfill. If screens were provided to remove glass and ceramic particles, the materials so removed also would require disposal by sanitary landfill.

Facilities for the Removal of Magnetic Materials Only The facilities required for one refuse processing unit with a 70-ton per hour processing capability, which is assumed for this study, providing for the removal of only magnetic metals from the milled material, are shown on Figure No. 3, and are described briefly as follows:

1. Two apron conveyor feeders of heavy-duty construction, installed in a pit to permit collection vehicles to discharge their loads to the conveyors without extra handling. Steel side walls would be required to confine the raw refuse to the conveyor surfaces.
2. One vibrating conveyor to distribute the raw refuse received in Item 1.
3. One steel pan apron conveyor to convey raw refuse from the vibrating conveyor to the primary mill.
4. One primary mill of the hammermill type, with a feed opening of about 5 by 8 feet. The mill would be driven by a direct connected 1,500 horsepower motor at 720 rpm.
5. One vibrating conveyor to receive milled refuse from the primary mill and feed it to a belt conveyor.
6. One belt conveyor to convey the milled refuse to a magnetic separator.
7. One magnetic drum separator.
8. One belt conveyor for conveying milled refuse with magnetic metals removed to a secondary mill.



BASIC LAYOUT OF REFUSE PROCESSING AND SHIPPING FACILITIES
 PROCESSING BY TWO STAGE MILLING AND MAGNETIC SEPARATION

- 9 One vibrating conveyor to provide uniform feed to the secondary mill.
- 10 One secondary mill of the hammermill type, capable of reducing the particle size to 1 inch, driven by a 1,500 horsepower motor at 720 rpm
- 11 One vibrating conveyor to convey the discharge from the secondary mill to a pneumatic conveying system
- 12 One air-lock feeder for the pneumatic conveying system, including a surge bin
- 13 One positive displacement-type blower for the pneumatic conveying system.
- 14 Pneumatic piping, from the blower and feeder to storage silos.
- 15 Dust control systems for the processing equipment
- 16 One belt conveyor to convey magnetic metal to trucks
- 17 Explosion control and fire protection equipment
- 18 One hoist or crane for servicing the mills

Comparative Processing Facilities The processing unit described in the preceding pages may be regarded as an independent entity. The logistics of handling raw refuse limit the maximum rate of delivery to a single processing unit. For facilities with required capacities greater than the single unit described herein, it therefore is regarded as necessary to provide multiples of the unit described. The only facilities which would be common for the individual units of such a multiple installation would be portions of the building, roadways, land, supervisory facilities and other facilities of a general plant nature.

There also are practical limitations of the size of a single processing plant. The population of the St. Louis metropolitan area, particularly the St. Louis County portion, is not heavily concentrated, at least not to the degree of concentration existing in certain of the larger metropolitan areas of the United States. It therefore appears that some limit should be established as to the maximum quantity of refuse which should be delivered to a single disposal facility. Considering probable hauling distances for the refuse collectors, most of whom are private haulers, it is believed that a single refuse processing plant for the St. Louis area should have a raw refuse capacity no greater than about 1,500 tons per day. This capacity could be accommodated, with some capacity to spare, by two processing lines of the type previously described, when operated on a two-shift basis. If one-shift operation were used, three processing units would be required.

In order to permit ready comparison of capital and operating costs for application of the proposed process, five combinations of facilities and operating schedules are given consideration herein:

1. One processing unit, operated one shift per day.
2. One processing unit, operated two shifts per day.
3. Two processing units, operated one shift per day.
4. Two processing units, operated two shifts per day.
5. Three processing units, operated one shift per day.

Consideration of these five combinations must include all phases of the process, including transport, receiving and firing facilities, in addition to the basic processing facilities. The discussions and estimated costs presented hereafter in this report reflect accommodation of these five combinations.

Facilities for Removal of Glass and Grit. The purpose of removing glass and grit obviously is to reduce the amount of non-burnable materials introduced to a boiler. However, even if the glass and grit were not removed from the milled material, the worst effect upon boiler operation might be merely an increase in the amount of bottom ash to be handled, which, according to Union Electric Company personnel, probably would not be a significant additional operating problem. Although the complexity of the processing plant would be increased by the addition of screens and their appurtenances, the size of the secondary mill probably could be reduced from that described previously. A significant disadvantage resulting from screening is that a greater quantity of unburnable material would require separate disposal. The screenings will contain substantial amounts of material with some calorific value, as indicated from the analytical results summarized in Table No. 14. Unless special provisions were made to recover the burnable fraction from the screenings, a part of the total fuel value of the milled refuse would be lost.

If screening facilities were provided to remove at least a portion of the glass and grit particles in the milled refuse, the equipment layout would become considerably more complex, as shown on Figure No. 4. Following the magnetic separator described in the preceding paragraphs, it would be necessary to install a system of chutes and conveyors for distributing the milled material from the primary mill to at least eight vibrating screens, each of which would have a screen surface of about 100 square feet. The screens would perform two separations, one for oversized material and one for small particles of glass and grit. Depending upon the requirements and configuration of the specific equipment selected for screening, as many as 15 additional conveyors would be needed to distribute the milled material to the

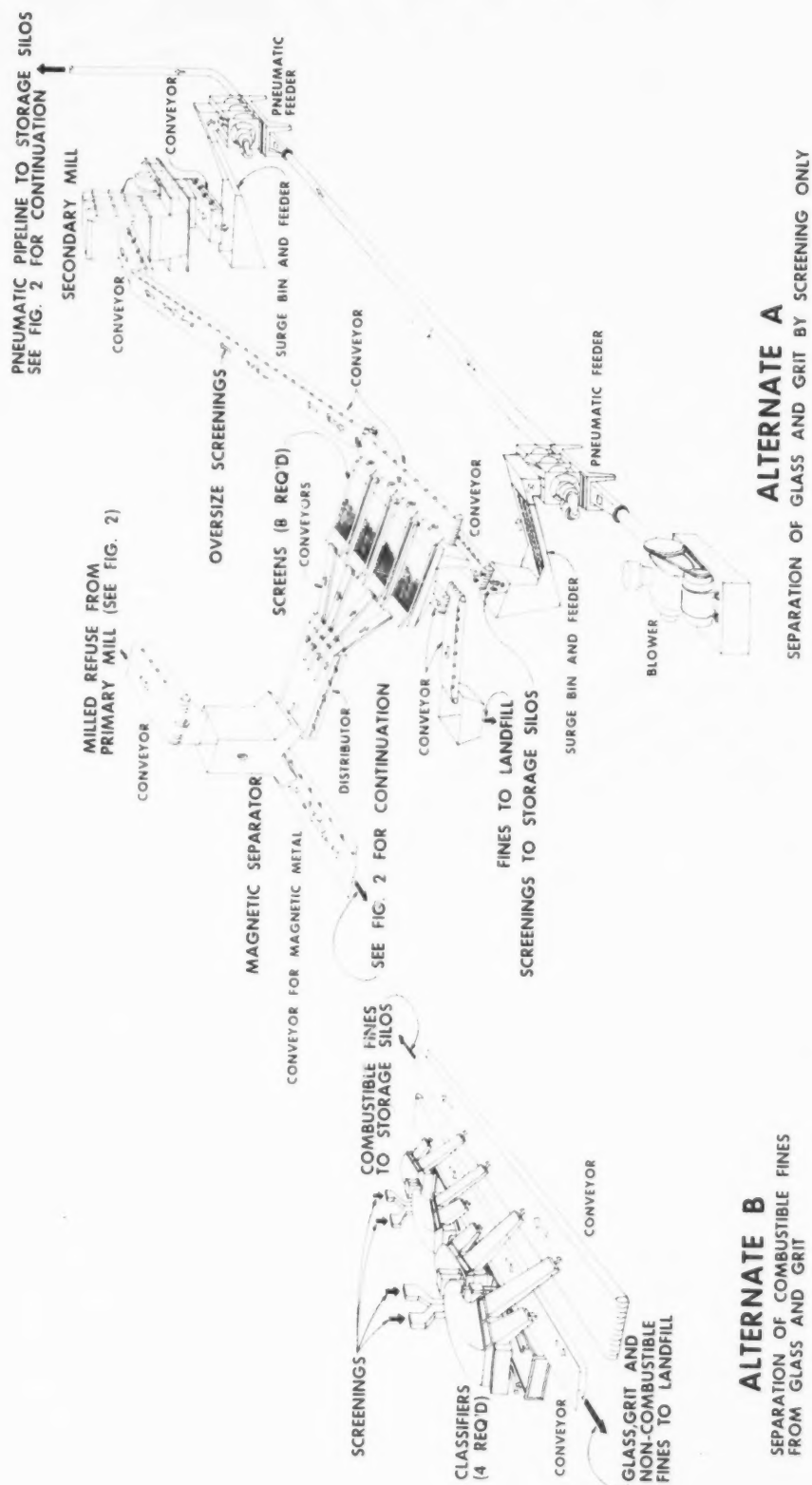


FIGURE NO. 4

screens and to collect the various fractions and discharge them to appropriate points. In addition, it is probable that two additional pneumatic feeders would be required because of the difficulty of providing for the finished product to be discharged at one point from several sources

As previously stated, the fines derived from the screening operation, as shown in Table No. 14, will have a significant calorific value, on the order of 2,145 to 3,900 Btu per pound as-delivered, since finely divided organic material will be screened out along with particles of glass and grit. Air-gravity separators are available which will separate most of the light organic materials from the glass and grit, also as shown on Figure No. 4

It is understood that screens of somewhat unique design presently are under development for processing materials such as milled refuse. Should such developmental efforts be successful, it might be possible to effect a more compact screening layout with a less complex distribution and collection system than is the case with screens which are commercially available at present.

Relative Costs of Facilities for Removing Magnetic Metal, Glass and Ceramic Particles Tabulated in the following are the estimated 1969 costs of 70-ton per hour processing units of three different designs. The three designs provide for the following:

Basic Unit To remove only magnetic metal.

Alternate A To remove glass and ceramic materials along with magnetic metals.

Alternate B Same as Alternate A, with additional provisions for recovering organic materials from screenings.

The estimated costs are presented in the following tabulation:

	<u>Basic Unit</u>	<u>Alternate A</u>	<u>Alternate B</u>
Site Preparation and Roadways	\$ 34,000	\$ 34,000	\$ 34,000
Building and Structures	763,000	890,000	890,000
Equipment, Mechanical and Electrical	<u>1,340,000</u>	<u>1,614,000</u>	<u>1,793,000</u>
Subtotal	\$2,137,000	\$2,538,000	\$2,717,000
Construction Contingencies	214,000	254,000	272,000
Engineering, Administration and Supervision	<u>192,000</u>	<u>228,000</u>	<u>244,000</u>
Total 1969 Estimated Cost	\$2,543,000	\$3,020,000	\$3,233,000

The additional capital cost of screening facilities to remove glass and ceramic materials thus is estimated to be a minimum of \$477,000. It is anticipated that additional operating problems, with attendant additional operating costs, also would exist if screening facilities were provided, due to the possibilities of blinding occurring on the screen surfaces and to the difficulties expected in maintaining uniform flow of material to and away from the screens. Since the value of removing glass and ceramic particles from the processed refuse may be questionable, it appears proper at this time to provide only for the removal of magnetic metals. This assumption is reflected in the remainder of this report.

TRANSPORTING FACILITIES

Under the assumption that the processing facilities will be some distance removed from the boiler plant, it is necessary that an efficient and practical means of transporting the prepared refuse be utilized. The four basic methods by which the prepared refuse could be transported are by rail, by barge, by pipeline, and by truck. Although all of these methods may deserve consideration under a given set of circumstances, certain of them are not as flexible as others and may not be applicable.

The loose bulk density of municipal refuse, after being milled and after magnetic metals have been removed, can be expected to be between 4 and 11 pounds per cubic foot. The material will compact to some degree by virtue of its own weight when piled, with resulting average densities of possibly 12 to 15 pounds per cubic foot. Variations in moisture content of the milled material should be the principal cause of variations in bulk density.

Since it is anticipated that the prepared refuse will be introduced into the boilers by pneumatic means, the material must be relatively loose and free-flowing when fed into the pneumatic system. Some compaction of the material for shipping is considered to be desirable, in order to increase pay loads and reduce shipping costs. It is anticipated, however, that the compaction should not be so great as to require an additional processing step at the point of delivery in order to regain the loose characteristics required to handle the material by pneumatic conveyors.

The transportation system used for transporting the supplementary fuel to a boiler plant must be sufficiently flexible to accommodate varying conditions. The prepared refuse may be required to be fired at different rates during different loadings of the boiler facilities, and it is probable that deliveries of the refuse to the boiler plant may be required at varying rates. In addition, deliveries may be required to be made to boilers in different locations. The means of transport therefore must permit such varying conditions, preferably without requiring large-scale storage facilities.

Bearing in mind that municipal refuse collection is performed one shift per day, five or six days per week, and that the processing facilities assumed

for purposes of this study will process the raw refuse in no more than two shifts, although the refuse will be fired to the boilers at a continuous rate on a 24-hour per day basis, it is obvious that some storage of the prepared material will be required. Depending upon the mode of operation, certain of the available methods of transport may permit this storage requirement to be met by the volume provided by the transporting conveyances, such as railroad cars or barges.

Transport by Rail If rail transport of the prepared refuse were used, there would be three basic practical methods of handling the material, in conventional box cars, in special cars equipped for dumping, or in separate closed containers hauled on flat cars. Discussion with the Missouri Pacific Railroad Company, which has a direct rail route to both the Meramec and Labadie power plants, has resulted in the conclusion that the quantity of material to be shipped would not be sufficient to justify the use of a special train with its required equipment and crew. If the railroad cars were used for storage of the daily refuse production, for one shipment per day of prepared refuse to the Meramec plant, under the Railroad's present switching schedule, four sets of cars would be necessary, with one set of cars being loaded, one set being unloaded, one set in transit to the power plant, and the fourth set in transit back to the processing plant. To reduce the number of cars required to two sets, storage silos would be required at both the processing plant and the power plant.

At the present time it is understood that conventional box cars would be available only as 40-foot cars. It is estimated that 16 of such cars would be required per shipment, with one shipment per day, to accommodate the production rate of a single processing unit operating one shift per day. This estimate assumes that about 29 tons of prepared refuse could be loaded in each car. A shipment of 16 cars per day would be sufficient to permit firing the supplementary fuel at a nominal rate of 19 tons per hour to the power plant. This mode of rail haul could result in a total of as many as 64 conventional 40-foot box cars being reserved for this service, since these cars could not be used for hauling grain or other such commodities without being thoroughly cleaned and disinfected. The loading of such cars could be performed with relative ease by pneumatic conveyors. The unloading of box cars would be more difficult, and could result in an undesirable housekeeping problem at the receiving end.

Special railroad cars could be constructed to transport the supplementary fuel. Such cars can be equipped to permit dumping from either the sides or the ends of the cars. Greater loadings can be achieved with such equipment, on the order of 50 to 60 tons per car, and the total number of cars would be correspondingly less than of conventional box cars. However, four sets of such cars would be required to provide continuity, unless storage silos were provided at both ends of the route. The required capital investment in this case would be excessive and the use of special cars for a relatively short haul does not appear practical.

The use of separate containers loaded on flat cars has the advantage of not requiring special rolling stock, and would permit loading and unloading with relative ease. However, the other disadvantages of rail haul would still be present and it is concluded that other means of transport are more practical for application in the St. Louis area.

Transport by Barge The use of barges for transporting supplementary fuel has a number of attractive features when the hauling distances and the scale of operations are large enough and when continuity of service requirements is assured. All major power plants are located near large bodies of water, which often are navigable. The Meramec plant is located on the Mississippi River and the Labadie plant on the Missouri River. Barge shipments of supplementary fuel would be possible in both cases, but would be subject to interruption. The two rivers are both subject to extreme flood stages, and barging necessarily would have to be interrupted during such extreme stages. A 9-foot navigation depth is maintained only nine months per year on the Missouri River. Ice conditions in winter also could interfere with barge traffic. If barges were used to transport the supplementary fuel to the power plants, some alternate means of transport would be required when barging is not possible. The large capital costs required for loading and unloading facilities, along with the cost of the barges, lead to the conclusion that barging is not as feasible as other means of transport for the St. Louis situation. This conclusion is reinforced by the relative inflexibility of barging and the relatively short distances the supplementary fuel must be transported.

Transport by Pipeline Pneumatic transport of materials similar to prepared refuse is generally limited to a distance of about one mile. It is conceivable that individual pneumatic systems could be applied in series, to achieve greater distances. Each of such systems would require a feed hopper, a rotary air-lock feeder, a blower, and an air-solids separation system at the discharge end. A series of such systems obviously would be difficult to maintain and control, and each transfer of material from one system to the next would result in a loss in efficiency. It may be reasonably concluded that unless the distance to be traversed is relatively short, say one mile or less, pneumatic conveying would not be practical.

Transport by Truck Transport of the supplementary fuel by truck would require a relatively low capital investment, although under some circumstances, such as in the case of long hauls, the operating costs may be expected to be somewhat higher than for other large-scale transporting methods. Truck transport offers substantial flexibility in operation, since individual trucks may be dispatched to suit variations in the demands of the receiving end of the system. For application of the proposed process, transport of the supplementary fuel by truck appears to be the most practical of the available methods, and will be considered to be the most appropriate for transporting the prepared refuse from the processing facilities considered herein to either the Meramec or the Labadie power plants.

The transport of refuse by trailer trucks from the processing facilities to the power plants will require certain special equipment and procedures. Transport trailers of 75 to 80 cubic yards nominal capacity would be rear-loaded at the processing plant from an elevated storage silo by means of a stationary packer. The milled material would be compacted in the trailers to achieve loads of about 20 tons. It is believed that with careful selection of tractors and trailers that loadings of this magnitude can be achieved without exceeding the allowable highway axle loadings. The trailers would be equipped with self-unloading mechanisms to permit unloading from the rear. For a daily quantity of 455 tons of supplementary fuel, equivalent to the production of one processing unit in one shift, about 23 trips per day, or eight trips per shift, would be necessary. As long as the hauling distance is no greater than about 25 miles, four tractor-trailer combinations would be required for this daily volume, one of which would be a spare. Three of the tractor-trailer units would be required to be in continuous service on a three-shift basis when the processing plant and the boiler plant are processing and firing the supplementary fuel at the 455 ton per day rate. Scheduling of the truck deliveries will require close supervision, to ensure that the rate of delivery is approximately equal to the rate of firing of the supplementary fuel.

The transporting facilities are considered to be comprised of:

1. Storage silos for milled refuse, located at the processing plant, equipped with live bottoms and conveyors to discharge to stationary packers.
2. Stationary packers to load transport trailers.
3. Tractor-trailer units of 75 to 80 cubic yard capacity, for hauling the supplementary fuel from the processing plant to the power plant.

The volume of storage for the supplementary fuel required, the number of stationary packers and the number of tractor-trailer units required to transport the fuel to the power plants, depend upon several interrelated factors. These factors include the rate of processing, the total daily production, the required rate of delivery to the power plant, the hauling distance, and the storage volume available at the power plant.

RECEIVING FACILITIES

The facilities required to receive the supplementary fuel at the power plants include the following:

1. Steel live-bottom hoppers set in a concrete pit, to receive the supplementary fuel delivered by the self-unloading

transport trailers. The hopper would have sufficient capacity to accommodate at least one truck load of prepared refuse. The live bottom would consist of multiple screw conveyors to assure discharge from the hopper.

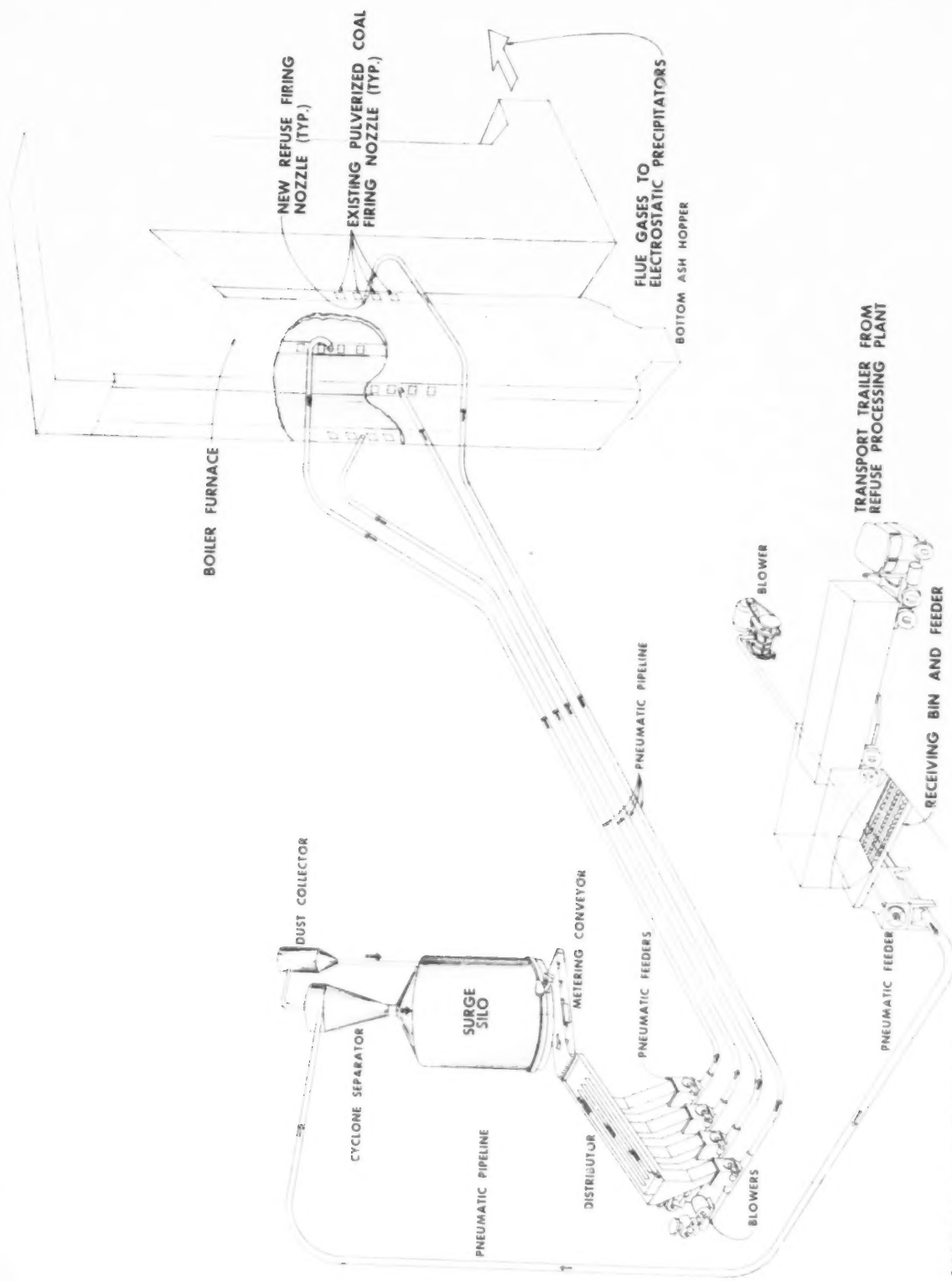
2. A rotary air-lock feeder, to introduce the supplementary fuel into a pressurized pneumatic pipeline
3. A positive displacement-type blower to provide the transporting air for the pneumatic system

All of the equipment at the receiving station would be enclosed in a building, including the truck dumping facilities. A diagram of the receiving station is shown on Figure No. 5. Unloading of the trucks would be performed by the truck drivers, who would merely be required to activate the unloading mechanisms on the trailers. Controls would be provided to ensure that the pneumatic system would not convey the material to the storage silo unless there were sufficient volume available in the silo to receive it.

STORAGE AND FIRING FACILITIES

The minimum facilities required to store and fire the supplementary fuel to boilers are considered to be as follows:

1. A pneumatic pipeline from the blower at the receiving station to a short-term storage silo.
2. Storage silos, equipped with live bottoms and dust control equipment
3. Conveyors equipped with weighing devices to control the rate of feed.
4. Vibrating distributors to serve as means of dividing the fuel equally to the burner feeders.
5. Heavy-duty air-lock feeders, one for each burner nozzle
6. Positive displacement-type blowers, one for each burner nozzle
7. Installation of burner nozzles, of sufficient capacity and in appropriate locations to feed the quantity of refuse desired
8. All necessary pneumatic piping from the blowers to each of the refuse burner nozzles
9. All necessary electrical wiring, interlocks and controls for the blowers, feeders, and other electrically powered equipment



BASIC LAYOUT OF REFUSE UNLOADING, METERING AND FEEDING FACILITIES AT POWER PLANT

FIGURE NO. 5

CAPITAL COST SUMMARY

The 1973 estimated capital costs of each of the five combinations of facilities and processing schedules considered for evaluation in this study are summarized in Table No 18

There is no specific provision in the facilities included in the estimates summarized in Table No 18 for spare equipment which would be used in case of a major breakdown. In each case, however, there is some provision for extra processing capability, since it is anticipated that processing normally would be confined to a maximum of two shifts per day, with the intention that hammermill maintenance and routine repairs would be performed during the second or third shifts. Whether a complete spare processing unit would be required for a specific case would depend upon the availability of alternate means of refuse disposal.

The facilities included in the estimates of capital costs are believed to be conservative. The processing of raw refuse at the rate considered applicable in this study has not been done before, and the pneumatic firing of prepared refuse into large utility boilers has not yet been attempted. It therefore is considered proper to provide for facilities which would accommodate the worst conditions to be anticipated, and which would permit reasonably flexible operation.

There are several areas in which economy in capital costs could be effected in permanent, long-range installations, providing full-scale tests were to show such economies to be feasible. Such economies might include the elimination of second-stage milling, smaller motors on the mills, increased conveyor speeds, which might reduce conveyor width, substitution of large volume bucket elevators for long belt conveyors, elimination of truck transport of prepared refuse, which could be effected if the processing and boiler plants were within one mile of each other, elimination of certain of the minor auxiliary equipment which was provided in the facilities for the convenience of boiler operating personnel, and economy in buildings and foundations which might be possible with an ideal plant site. The cost estimates of the permanent full-scale facilities, as presented, do not assume that any of the potential economies could be effected.

TABLE NO. 18

CAPITAL COST SUMMARY

	One Processing Unit		Two Processing Units		Three Processing Units
	One-Shift Operation	Two-Shift Operation	One-Shift Operation	Two-Shift Operation	One-Shift Operation
<u>Processing Facilities</u>					
Site Preparation and Roadways	\$ 34,000	\$ 34,000	\$ 80,000	\$ 80,000	\$ 120,000
Building and Structures	763,000	763,000	1,310,000	1,310,000	1,930,000
Mechanical, Elec. and Equipment	1,340,000	1,340,000	2,740,000	2,740,000	4,070,000
Subtotal	\$2,137,000	\$2,137,000	\$4,130,000	\$4,130,000	\$6,120,000
Construction Contingencies	214,000	214,000	413,000	413,000	612,000
Engineering, Adminis. and Supervision	192,000	192,000	372,000	372,000	451,000
1969 Estimated Construct. Cost	\$2,543,000	\$2,543,000	\$4,915,000	\$4,915,000	\$7,183,000
Plant Site	150,000	150,000	200,000	200,000	250,000
Landfill Site	125,000	125,000	175,000	175,000	200,000
Total 1969 Est. Proj. Cost	\$2,818,000	\$2,818,000	\$5,290,000	\$5,290,000	\$7,633,000
Escalation to 1973	609,000	609,000	1,142,000	1,142,000	1,648,000
Total 1973 Estimated Cost	\$3,427,000	\$3,427,000	\$6,432,000	\$6,432,000	\$9,281,000
<u>Transporting Facilities</u>					
Structures	\$ 20,000	\$ 28,000	\$ 40,000	\$ 42,000	\$ 60,000
Mechanical, Elec. and Equipment	137,000	166,000	254,000	239,000	371,000
Subtotal	\$ 157,000	\$ 194,000	\$ 294,000	\$ 281,000	\$ 431,000
Construction Contingencies	16,000	19,000	29,000	28,000	43,000
Engineering, Adminis. and Supervision	14,000	18,000	27,000	25,000	39,000
1969 Estimated Construct. Cost	\$ 187,000	\$ 231,000	\$ 350,000	\$ 334,000	\$ 513,000
Transfer Tractors and Trailers	140,000	245,000	245,000	350,000	350,000
Total 1969 Project Cost	\$ 327,000	\$ 476,000	\$ 595,000	\$ 684,000	\$ 863,000
Escalation to 1973	71,000	103,000	129,000	148,000	186,000
Total 1973 Estimated Cost	\$ 398,000	\$ 579,000	\$ 724,000	\$ 832,000	\$1,049,000
<u>Receiving Facilities</u>					
Site Preparation and Roadways	\$ 5,000	\$ 10,000	\$ 10,000	\$ 15,000	\$ 15,000
Building and Structures	63,000	63,000	63,000	125,000	125,000
Mechanical, Elec. and Equipment	87,000	87,000	87,000	175,000	175,000
Subtotal	\$ 155,000	\$ 160,000	\$ 160,000	\$ 315,000	\$ 315,000
Construction Contingencies	15,500	16,000	16,000	31,500	31,500
Engineering, Admin., and Supervision	14,000	14,500	14,500	28,500	28,500
1969 Estimated Construct. Cost	\$ 184,500	\$ 190,500	\$ 190,500	\$ 375,000	\$ 375,000
Escalation to 1973	39,500	41,500	41,500	81,000	81,000
Total 1973 Estimated Cost	\$ 224,000	\$ 232,000	\$ 232,000	\$ 456,000	\$ 456,000
<u>Firing Facilities</u>					
Structural Modifications	\$ 40,000	\$ 80,000	\$ 80,000	\$ 80,000	\$ 150,000
Elec. and Mechanical Modifications	5,000	10,000	10,000	10,000	25,000
Boiler Modifications	40,000	100,000	100,000	100,000	100,000
Mechanical, Elec. and Equipment	271,000	482,000	482,000	542,000	556,000
Subtotal	\$ 356,000	\$ 672,000	\$ 672,000	\$ 732,000	\$ 831,000
Construction Contingencies	36,000	67,000	67,000	74,000	83,000
Engineering, Admin., and Supervision	32,000	61,000	61,000	66,000	75,000
1969 Estimated Construct. Cost	\$ 424,000	\$ 800,000	\$ 800,000	\$ 872,000	\$ 989,000
Escalation to 1973	92,000	173,000	173,000	188,000	213,000
Total 1973 Estimated Cost	\$ 516,000	\$ 973,000	\$ 973,000	\$1,060,000	\$1,202,000
Total Estimated Capital Requirements	\$4,565,000	\$5,211,000	\$8,361,000	\$8,780,000	\$11,988,000

PART VIII

ECONOMIC ASPECTS OF PROCESS

GENERAL

The net cost of refuse disposal by the proposed process may be considered to be the cost of processing, transporting and firing the prepared refuse to boilers as supplementary fuel, less the value of the prepared material as fuel. This net cost may be compared to the cost of disposal of raw refuse by other means. All of such costs may reasonably be expected to increase in the future, at a rate at least as great as that experienced over the past decade.

VARIABLES HAVING BEARING UPON ECONOMICS OF PROCESS IN A GIVEN AREA

There are several variable factors which would significantly affect the economic feasibility of the proposed process in a given metropolitan area.

Value of Refuse as Fuel. From data published by the Federal Power Commission, the cost of coal burned in the larger suspension-fired utility boilers varies substantially. In the St. Louis area, this cost is presently relatively low, on the order of \$0.20 to \$0.21 per million Btu. In New York City the fuel cost is in the range of \$0.36 to \$0.37 per million Btu. Assuming the average fuel value of prepared refuse to be 5,000 Btu per pound, its dollar value as fuel therefore would be as high as \$3.60 to \$3.70 per ton in the New York area. Similarly, in the Chicago area its value as fuel would be about \$2.80 to \$3.00 per ton; in the Detroit area, about \$2.60 to \$3.00 per ton; in the Cleveland area, about \$2.60 per ton; in the Philadelphia area, about \$3.10 per ton; and in the Milwaukee area, about \$3.00 per ton.

The Union Electric Company has projected fuel costs for its facilities to 1974. By that date fuel costs for the Meramec Plant are projected to increase to \$0.30 to \$0.31 per million Btu, and for the Labadie Plant to almost \$0.27 per million Btu. In these cases, 5,000 Btu per pound refuse would have a value as fuel of about \$3.05 to \$3.10 per ton at the Meramec Plant and about \$2.70 per ton at the Labadie Plant by 1974. It appears probable that fuel costs in other parts of the country also will increase substantially.

Availability of Power Plants for Burning Refuse. The final judgment as to whether the power producing facilities of a given utility would utilize prepared refuse as a supplementary fuel is the prerogative of the utility. The profits of a utility are normally controlled by a State agency, such as a Public Service Commission, or the equivalent thereof, and although a

utility may be given concessions of some kind because of their participation in an attempt to alleviate a community problem, such as the disposal of refuse, there is no known specific precedent for such concessions. It, of course, is conceivable that the controlling agencies would grant concessions to the utilities if a significant overall public benefit would result from the application of a process similar to that proposed.

The physical adaptability of a specific boiler unit for burning refuse as a supplementary fuel also is subject to the judgment of the involved utility as well as of the manufacturer of the boiler. In general, with some modifications, which in most cases should be relatively minor in nature, it is considered that most tangentially-fired and front-fired boilers could be adapted to the process. Each unit considered for such adaptation, however, should be studied with regard to the potential effects upon the boiler and its operation, including those matters discussed in Part VI of this report.

Proximity of Refuse Processing Facilities to Power Plant In many metropolitan areas, such as in the St. Louis area, the power plants which appear to be the most attractive for burning small percentages of prepared refuse as fuel are some miles removed from the center of refuse production. This circumstance makes necessary provision for the transport of the prepared refuse to the power plants, with an attendant additional cost. If a refuse processing facility could be located within about one mile of a power plant adaptable for burning prepared refuse, the prepared material could be conveyed pneumatically to the plant, thereby effecting a substantial savings over the comparable transportation costs by other means. This premise is based upon the assumption that the preparation plant would be near a major center of refuse production. It would appear that the New York City area would be particularly attractive as a location in which the transportation costs of the prepared material could be minimized.

Costs of Refuse Disposal by Other Means The only two presently accepted methods of refuse disposal in general use are sanitary landfill and incineration. The costs of disposal by either of these methods vary widely, depending upon the specific circumstances applicable to a given area. Caution must be exercised in comparing such costs. For example, the overall costs of sanitary landfill normally should include the hauling costs from the applicable center of refuse production, since sanitary landfill operations usually are some distance removed from such centers. Incinerators, on the other hand, often are located near the applicable center of refuse production, so that the effects of hauling distances are minimized.

The costs of refuse disposal by large-scale sanitary landfill, when operated in accordance with reasonably high standards, and if the accounting of the costs reflects self-perpetuation of the facilities, will be in the range of \$1.25 to \$1.75 per ton, without including hauling costs. The costs of hauling raw refuse to the disposal site in packer-type collection vehicles will be in the general range of \$0.10 to \$0.15 per ton mile. If one-way

hauling distances are on the order of 12 miles or more, transfer stations and transfer truck-trailer units may be more economical than hauling in collection vehicles, but the overall hauling costs will still be of the same order of magnitude.

The costs of refuse disposal by incineration, as reported by various agencies, vary widely. For incinerators incorporating acceptable means of air pollution control, the total applicable unit costs will range from \$5 to \$12 per ton.

OPERATING COSTS OF EXISTING ST. LOUIS INCINERATORS

The nominal capacity of the existing City of St. Louis refuse incinerators is 400 tons of raw refuse per 24-hour day for each of the two plants. The average quantity of refuse delivered per operating day approaches 900 tons, and maximum daily quantities occasionally are on the order of 1,300 to 1,400 tons. This consistent overloading of the existing facilities imposes severe maintenance problems, since it is difficult to schedule shutdowns for major maintenance and repair work. As a result, the expenditures for maintenance and repairs have been inadequate in the past, thereby reflecting unrealistic operation and maintenance costs. Continuation of the policy of not providing sufficient funds for maintenance and repair almost certainly will result in deterioration of the existing facilities to a point at which portions of the facilities will not be operable.

An expansion of the North City Incinerator is planned, consisting of the addition of one 300-ton per day continuous furnace. It is anticipated that this addition will be in operation by mid-1971.

Table No. 19 presents the operating costs for the two incinerators as listed in the annual reports for the fiscal years 1962-63 to 1967-68, inclusive. These costs have been adjusted to reflect social security and other payroll costs as well as the estimated cost of process water. Such costs have not been included in the published operating costs in the past.

Also included in Table No. 19 are the estimated projected operation and maintenance costs of the incinerators to the fiscal year 1972-73. These projected costs include provision for the additional manpower required to maintain and operate the facilities in accordance with realistic standards. It is believed that such provisions are necessary to ensure continued operation of the plants. Labor costs have been escalated at the same rate indicated by past plant records. The projections also reflect estimated additional operating costs for air pollution control equipment which is in the process of being installed. It will be noted that by 1972-73 the estimated operation and maintenance costs are on the order of \$3.38 per ton of refuse incinerated. These costs do not reflect provision for the equivalent annual cost of the capital investment in the two plants.

TABLE NO. 19

ANNUAL COSTS
CITY OF ST. LOUIS INCINERATORS

OPERATION AND MAINTENANCE COSTS	1962 - 1963	1963 - 1964	1964 - 1965	1965 - 1966	1966 - 1967	1967 - 1968	1968 - 1969 (a)	1969 - 1970 (a)	1970 - 1971 (a)	1971 - 1972 (a)	1972 - 1973 (a)
Salaries and Wages	\$280,606	\$282,740	\$291,315	\$328,206	\$354,140	\$400,758	\$410,000	\$488,000	\$508,000	\$561,000	\$594,000
Social Security, Pension, etc. (a)	28,100	28,300	29,100	32,800	35,400	40,100	41,000	48,800	50,800	56,100	59,400
Maintenance Materials	13,020	14,858	16,843	21,769	23,646	26,670	25,000	45,000	45,000	50,000	50,000
Equipment Replacement	1,384	1,275	52,725	25,917	1,625	10,159	12,000	30,000	30,000	35,000	35,000
Repairs	6,552	2,651	6,298	7,951	25,979	16,950	20,000	30,000	30,000	35,000	35,000
Electricity	11,851	12,452	13,841	13,250	14,238	14,000	14,700	14,900	15,100	20,000	20,000
Water (a)	19,200	19,200	19,200	19,200	19,200	19,200	19,200	35,000	52,900	60,000	60,000
Supplies and Miscellaneous	12,226	10,921	11,117	11,954	21,233	24,277	25,000	25,000	25,000	25,000	25,000
Total Operating & Maintenance Cost	\$372,639	\$372,397	\$440,499	\$461,047	\$495,461	\$552,114	\$566,900	\$716,700	\$756,800	\$842,100	\$878,400
<u>AMORTIZATION COSTS</u>											
1955 Bonds	\$237,000	\$237,000	\$237,000	\$237,000	\$237,000	\$237,000	\$237,000	\$237,000	\$237,000	\$237,000	\$237,000
1967 Bonds (First Issue)	-	-	-	-	-	-	-	-	174,000	174,000	174,000
1967 Bonds (Second Issue)	-	-	-	-	-	-	-	55,000	55,000	55,000	55,000
Total Amortization Cost	\$237,000	\$237,000	\$237,000	\$237,000	\$237,000	\$237,000	\$237,000	\$292,000	\$466,000	\$466,000	\$466,000
Tons of Refuse Incinerated	223,145	228,426	223,888	242,143	242,822	240,980	245,000	249,000	252,000	256,000	260,000
Operation & Maintenance Cost, per ton	\$1.67	\$1.63	\$1.96	\$1.90	\$2.04	\$2.29	\$2.31	\$2.88	\$3.00	\$3.29	\$3.38
Amortization Cost, per ton	\$1.06	\$1.04	\$1.06	\$0.98	\$0.98	\$0.99	\$0.97	\$1.17	\$1.85	\$1.82	\$1.79
Total Cost, per ton	\$2.73	\$2.67	\$3.02	\$2.88	\$3.02	\$3.28	\$3.28	\$4.05	\$4.85	\$5.11	\$5.17

(a) Estimated

The two existing incinerators were constructed from the proceeds of a bond issue approved in 1955. The capitalized value of the existing facilities is about \$3,800,000 (both plants). The bonds sold for these facilities bear a 2.25 per cent per year interest rate for a 20-year term. The annual depreciation plus interest is therefore approximately \$237,000 per year. The bonds from which the current incinerator improvements are being financed were sold in 1967. Of a total of about \$3,200,000 applicable to incinerator improvements, \$2,500,000 bonds were sold at an average interest rate of 3.38 per cent and \$700,000 at an average interest rate of 4.69 per cent, both issues for a 20-year term. The annual depreciation, plus interest, for the \$2,500,000 issue would be about \$174,000 per year, and for the \$700,000 issue, about \$55,000 per year. All bonds sold for this purpose were of the general obligation type, payable from property taxes. It will be noted that the estimated total cost shown in Table No. 19, including amortization, is \$5 17 per ton in the 1972-73 fiscal year.

In an effort to effect economy in disposing of refuse, the City of St. Louis is giving consideration to the possibility of utilizing sanitary landfill as a substitute for incineration, at least to a degree which would permit closing one of the two City incinerators. There are no long-range sanitary landfill sites within the City of St. Louis, and it is probable that if sanitary landfill were utilized, the City would have to rely upon disposal sites some miles from the centers of refuse production. Long hauling distances, of say 24 miles per round trip, would probably require truck transfer stations. As an order of magnitude estimate, the costs of disposal by sanitary landfill, including operation and amortization costs of a transfer station, together with hauling costs from the transfer station to the disposal site, are estimated to be the equivalent of \$3.50 to \$4.50 per ton, with a minimum capital requirement of \$750,000 to \$1,000,000. Such unit costs are thus somewhat less than those applicable locally for incineration, when appropriate amortization costs are included. However, the amortization of the City's incineration facilities will continue whether they are used or not. It appears probable that the net out-of-pocket costs to the City would be greater for disposal by sanitary landfill with transfer stations, than it would be in continuing operation of the incinerators.

ESTIMATED REFUSE DISPOSAL COSTS APPLICABLE TO ST. LOUIS COUNTY

The presently prevailing method of refuse disposal in St. Louis County is sanitary landfill. The voters of St. Louis County, however, have authorized the construction of two refuse incinerators, the construction of which has been temporarily delayed because of court action regarding plant sites. In the meantime the existing sanitary landfills are being exhausted, and the authorities apparently are reluctant to authorize the establishment of new landfill sites. It appears, therefore, that comparisons of cost of the proposed process of burning refuse as supplementary fuel in boilers most appropriately could be made against the applicable costs of conventional

incineration. The estimated operation and maintenance costs of the contemplated St. Louis County incinerators is \$3.75 per ton, based upon anticipated 1973 conditions. Amortization of the facilities is estimated to be the equivalent of \$2.78 per ton. The total equivalent unit cost of disposal by incineration in St. Louis County is thus estimated to be about \$6.53 per ton.

COSTS OF FUEL FOR UTILITY BOILERS

The projected estimated cost of coal for the Meramec power plant for 1973 is about \$6.40 per ton, and for the Labadie Plant about \$5.90 per ton. Assuming the prepared refuse to have a calorific value of 5,000 Btu per pound, its value as fuel in 1973 therefore would be about \$3.00 per ton at the Meramec Plant, and about \$2.55 per ton at the Labadie Plant.

EQUIVALENT ANNUAL COSTS OF PROPOSED PROCESS

Under the assumption previously outlined, that the maximum reasonable capacity of a refuse disposal facility in the St. Louis area is about 1,500 tons per day, Table No. 20 summarizes the pertinent data and estimated equivalent annual costs of the required facilities. It should be understood that more concentrated metropolitan areas could support refuse disposal facilities of greater capacity. Table No. 20 presents costs for processing plants consisting of one, two and three processing units, operating one shift per day, and with the one and two unit plants operating two shifts per day.

The sites of the plants listed in Table No. 20 are assumed to be within 25 miles of the power plants adaptable for burning refuse as supplementary fuel.

Amortization costs are computed upon the basis of financing by means of general obligation bonds, with a 20-year term and an annual interest rate of 5.0 per cent.

It will be noted that the lowest unit costs listed in Table No. 20 are for two-shift operation of the facilities on a 6-day per week basis. This is to be expected because of the greater use made of the capital investment by operating on the extended schedules, and the correspondingly greater amount of material processed.

ECONOMIC COMPARISONS

The net cost of the disposal of refuse by the proposed process may be computed by subtracting the value of the prepared refuse as fuel from the

TABLE NO. 20

EQUIVALENT ANNUAL COSTS AND UNIT COSTS

	One Processing Unit		Two Processing Units		Three Processing Units
	One-Shift Operation	Two-Shift Operation	One-Shift Operation	Two-Shift Operation	One-Shift Operation
Raw Refuse Processed, T/day	490	980	980	1,470	1,470
Raw Refuse Processed, T/yr. 5-Day Operation	127,400	254,800	254,800	382,200	382,200
Raw Refuse Processed, T/yr., 6-Day Operation	152,880	305,760	305,760	458,640	458,640
Supplementary Fuel Produced, T/day	453	906	906	1,359	1,359
Supplementary Fuel Produced, T/yr., 5-Day Operation	117,780	235,560	235,560	353,340	353,340
Supplementary Fuel Produced, T/yr., 6-Day Operation	141,336	282,672	282,672	424,008	424,008
Total Estimated Capital Cost	\$4,565,000	\$5,211,000	\$8,361,000	\$8,780,000	\$11,988,000
<u>Operation and Maintenance Costs (5-Day per Week Operation)</u>					
<u>Processing Plant</u>					
Labor	\$ 104,400	\$ 208,800	\$ 156,100	\$ 312,200	\$ 207,800
Hammermill Maintenance	68,400	136,800	136,800	205,200	205,200
Misc. Equipment Maintenance	15,000	20,000	20,000	25,000	35,000
Utilities	45,200	90,400	90,400	135,600	135,600
Building Depreciation	7,000	7,000	13,000	13,000	24,000
Equipment Replacement	40,000	50,000	80,000	100,000	161,200
Supplies and Miscellaneous	15,000	20,000	20,000	25,000	30,000
Administration	20,000	25,000	25,000	30,000	35,000
Total Estimated Processing Cost	\$ 315,000	\$ 558,000	\$ 541,300	\$ 846,000	\$ 833,800
<u>Transport Facilities</u>					
Labor	\$ 89,100	\$ 178,200	\$ 178,200	\$ 237,600	\$ 237,600
Equipment Replacement	22,200	35,000	40,000	50,000	62,500
Truck Operating Expense	35,000	70,000	70,000	105,000	140,000
Total Estimated Transport Cost	\$ 146,300	\$ 283,200	\$ 288,200	\$ 392,600	\$ 440,100
<u>Receiving and Firing Facilities</u>					
Equipment Maintenance	\$ 10,000	\$ 15,000	\$ 15,000	\$ 20,000	\$ 20,000
Equipment Replacement	12,000	31,400	31,400	31,400	29,400
Power	4,700	9,300	9,300	14,000	14,000
Total Est. Receiving and Firing Costs	\$ 26,700	\$ 55,700	\$ 55,700	\$ 65,400	\$ 63,400
Total Est. Oper. and Maint. Cost - 5-Day Operation	\$ 488,000	\$ 896,900	\$ 885,200	\$1,304,000	\$1,337,300
Total Est. Oper. and Maint. Cost - 6-Day Operation	\$ 586,000	\$1,075,000	\$1,060,000	\$1,565,000	\$1,605,000
<u>Amortization Costs</u>	\$ 366,000	\$ 418,000	\$ 670,000	\$ 704,000	\$ 962,000
<u>Equivalent Unit Costs - 5-Day Oper.</u>					
Oper. and Maint., per ton of Raw Refuse	\$ 3.83	\$ 3.52	\$ 3.47	\$ 3.41	\$ 3.50
Amortization, per ton of Raw Refuse	2.87	1.64	2.63	1.84	2.52
Total Unit Cost, per ton of Raw Refuse	\$ 6.70	\$ 5.16	\$ 6.10	\$ 5.25	\$ 6.02
Oper. and Maint., per ton of Supplementary Fuel	\$ 4.15	\$ 3.81	\$ 3.76	\$ 3.69	\$ 3.78
Amortization, per ton of Supplementary Fuel	3.11	1.78	2.85	1.99	2.72
Total Unit Cost, per ton of Supplementary Fuel	\$ 7.26	\$ 5.59	\$ 6.61	\$ 5.68	\$ 6.50
<u>Equivalent Unit Costs - 6-Day Oper.</u>					
Oper. and Maint., per ton of Raw Refuse	\$ 3.83	\$ 3.52	\$ 3.47	\$ 3.41	\$ 3.50
Amortization, per ton of Raw Refuse	2.40	1.37	2.19	1.54	2.05
Total Unit Cost, per ton of Raw Refuse	\$ 6.23	\$ 4.89	\$ 5.66	\$ 4.95	\$ 5.55
Oper. and Maint., per ton of Supplementary Fuel	\$ 4.15	\$ 3.81	\$ 3.76	\$ 3.69	\$ 3.78
Amortization, per ton of Supplementary Fuel	2.59	1.48	2.37	1.66	2.27
Total Unit Cost per ton of Supplementary Fuel	\$ 6.74	\$ 5.29	\$ 6.13	\$ 5.35	\$ 6.05

total unit cost of processing, transporting and firing the supplementary fuel. Thus, considering the most attractive comparison with a processing plant, operated two shifts per day, six days per week, on a 1973 basis, the unit cost per ton of supplementary fuel for both a one-unit and a two-unit plant, is in the range of \$5.29 to \$5.35 per ton. From this value may be subtracted \$3 per ton as the value of the supplementary material as fuel. The net cost of refuse disposal by this means therefore may be considered to be \$2.29 to \$2.35 per ton. Even on the least attractive basis, with a one-unit processing facility operated one shift per day, five days per week, the net cost of disposal would be \$4.26 per ton.

These net disposal costs may be compared directly with the costs of disposal by other means, tabulated as follows:

	Most Attractive Case cost/ton	Least Attractive Case cost/ton
Unit cost of processing, transporting and firing the supplementary fuel	\$5.29	\$7.26
Value of refuse as supplementary fuel	<u>3.00</u>	<u>3.00</u>
Net Cost of Disposal	\$2.29	\$4.26
Cost of Disposal by Incineration		
City of St. Louis	\$5.17	\$5.17
St. Louis County	6.53	6.53
Cost of Disposal by Sanitary Landfill, City of St. Louis (including transfer station)	\$4.00	\$4.00

It will be noted that even for the least attractive case, there is a significant economic advantage of the proposed process over incineration. When compared to disposal by sanitary landfill with transfer stations, the net cost of disposal by the proposed process is competitive.

Municipal officials often are concerned more with operation and maintenance costs than with the amortization of bond issues, because of the difficulties sometimes experienced in preparing annual budgets and in securing approval of the budgets by appropriate authorities. If only operation and maintenance costs are compared, the comparisons would be as follows:

	Most Attractive Case <u>cost/ton</u>	Least Attractive Case <u>cost/ton</u>
Operation Unit Cost of Processing, Transporting and Firing Supplementary Fuel	\$3.69	\$4.15
Value of Refuse as Supplementary Fuel	<u>3.00</u>	<u>3.00</u>
Net Cost of Disposal	\$0.69	\$1.15
Operating Cost of Incinerators		
City of St. Louis	\$3.38	\$3.38
St. Louis County	3.75	3.75
Operating Cost of Sanitary Landfill (including Transfer Station)	\$3.00	\$3.00

PART IX

POTENTIAL IMPACT OF PROCESS

GENERAL

Assuming full scale, long-term facilities were to be constructed for permanent application of the process, there could be substantial effects upon the costs of the production of electricity as well as upon the efficiency and costs of the disposal of solid wastes, at least in certain areas of the country. It would be misleading to generalize to too great a degree on such benefits, such as by reference to total national power production, coal consumption, refuse production, or to population, since it is not reasonable to consider the process to be universally applicable.

POTENTIAL APPLICATION TO EXISTING POWER PLANTS

One way of evaluating the effects of the process without undue exaggeration is by applying the process empirically to certain selected existing boiler plants in various parts of the country. The existing plants given consideration in this empirical application are listed in Table No. 21. The basic data included in Table No. 21 were extracted from the Federal Power Commission publication "Steam-Electric Plant Construction Cost and Annual Production Expenses - Twentieth Annual Supplement - 1967 "

At the present stage of evaluation, in considering the data in Table No. 21, it appears proper to impose certain limitations on the application of the proposed process. These limitations may, depending upon specific circumstances, be unduly restrictive in some cases, and too lenient in others. For purposes of discussion, the assumed limitations are listed as follows:

1. Table No. 21 lists only those plants which are in reasonably close proximity to the larger metropolitan areas. This limitation may be too restrictive, since long hauling distances may be well justified in some cases.
2. In general, the plants listed are above 500 megawatts in capacity, although there are certain plants of smaller capacity included as being representative of specific areas. There obviously are many plants of less than 500 megawatt capacity which might be considered appropriate for burning prepared refuse
3. The tabulated comparisons are limited to those power plants equipped for the suspension firing of pulverized coal, or of

TABLE NO. 21
STEAM ELECTRIC PLANTS BURNING PULVERIZED COAL
1967

Plant	Utility	Metropolitan Area	Capacity m.w.	Fuel Cost mills/kwh	Oper. Cost mills/kwh	Total Prod. Cost mills/kwh	Coal Burned 1,000 tons	Coal Cost per ton	Coal Cost cents per million Btu	Fuel Value Btu/lb	Annual Value 10% Coal	Rate Refuse = 10% Coal tons/yr	Pop. Served for Refuse = 10% Coal
Dickerson	Petonec Elec. Power	Washington, D.C.	586 (a)	2.71 (a)	0.47 (a)	3.18 (a)	1,400 (a)	\$ 7.52 (a)	29.84 (a)	12.55 (a)	\$ 977,000 (b)	364,000	500,000 (c)
McDonough	Georgia Power	Atlanta, Ga.	598	2.35	0.37	2.72	1,623	6.23	25.29	12.325	886,000	390,000	535,000
Crawford	Commonwealth Edison	Chicago, Ill.	701	2.76	0.76	3.52	1,539	5.79	28.01	10.325	892,000	356,000	485,000
Fisk	Commonwealth Edison	Chicago, Ill.	601	3.11	1.56	4.67	1,175	6.02	29.92	10.066	708,000	263,000	360,000
Will County	Commonwealth Edison	Chicago, Ill.	1,268	2.67	0.61	3.28	2,418	5.70	27.60	10.321	1,660,000	684,000	935,000
Wood River	Illinois Power	St. Louis, Mo.	650	1.92	0.59	2.51	1,682	4.26	19.15	11.111	713,000	415,000	570,000
State Line	Commonwealth Edison (Ind.)	Chicago, Ill.	972	2.34	0.69	3.03	1,977	5.26	23.41	11.222	1,040,000	494,000	675,000
River Rouge	Commonwealth Edison	Chicago, Ill.	943	2.47	0.71	3.18	2,166	6.70	25.80	12.360	1,340,000	577,000	796,000
Trenton Channel	Detroit Edison	Detroit, Mich.	560	4.00	2.28	6.28	1,277	7.35	35.90	9.669	716,000	384,000	480,000
Montrose	Kansas City Power & Light	Kansas City, Mo.	563	2.15	0.66	2.79	1,790	4.00	20.70	13.653	938,000	281,000	385,000
Astoria	Consolidated Edison	New York, N.Y.	1,580	3.83	1.86	5.69	1,929	10.08	36.85	13.657	1,055,000	508,000	685,000
Savannah	Consolidated Edison	New York, N.Y.	1,827	3.60	1.47	5.07	1,975	5.59	22.88	11.584	1,055,000	508,000	685,000
Beckford	Clim. Gas & Elec.	Cincinnati, O.	760	2.55	1.05	3.60	1,117	6.25	26.30	11.899	698,000	296,000	405,000
Lake Shore	Phila. Electric	Philadelphia, Pa.	318	3.24	0.62	3.86	1,590	8.37	31.10	13.471	1,330,000	476,000	650,000
Eddystone	Virginia Elec. & Power	Norfolk, Va.	649	3.13	0.68	3.81	1,207	8.42	31.50	13.912	1,015,000	358,000	490,000
Portsmouth	Wisconsin Elec. Power	Milwaukee, Wis.	300	2.67	0.48	3.15	1,225	7.00	29.37	11.941	858,000	324,000	445,000
N. Oak Creek	Wisconsin Elec. Power	Milwaukee, Wis.	1,170	2.67	0.48	3.15	1,225	7.00	29.37	11.941	858,000	324,000	445,000
Norskalk Harbor	Conn. Light & Power	Bridgewater, Conn.	375	2.92	0.75	3.67	1,031	7.03	29.63	12.684	730,000	262,000	365,000
Dunkirk	Niagara Mohawk	Buffalo, N.Y.	626	2.72	0.52	3.24	1,337	7.70	29.09	13.287	1,045,000	393,000	540,000
Huntley	Niagara Edison	Buffalo, N.Y.	426	2.72	0.52	3.24	1,337	7.70	29.09	13.287	1,045,000	393,000	540,000
Portland	Peab. Power & Light	Reading, Pa.	395	2.87	0.61	3.48	1,004	8.62	31.30	13.402	1,170,000	470,000	645,000
Bruner Island	Phila. Electric	Philadelphia, Pa.	417	2.97	1.00	3.97	870	8.46	31.30	13.402	1,090,000	484,000	635,000
Crabtree	S. Penn. Power	Pittsburgh, Pa.	448	1.96	0.57	2.53	2,293	4.69	18.67	11.311	601,000	263,000	360,000
Michell	Commonwealth Edison	Chicago, Ill.	1,862	2.23	0.50	2.73	4,242	4.85	22.57	10.755	2,035,000	1,010,000	1,380,000
Joliet	Commonwealth Edison	Chicago, Ill.	1,042	2.65	0.70	3.35	1,953	5.63	26.01	10.627	1,039,000	469,000	640,000
Knocksgang	Indianapolis Power & Lt.	Indianapolis, Ind.	383	2.63	0.79	3.42	840	5.64	28.40	11.562	462,000	210,000	290,000
Stonah River	Pub. Service of Ind.	Terre Haute, Ind.	521	2.65	0.61	3.26	1,497	4.43	20.16	10.983	664,000	369,000	500,000
Ashtabula	Cleveland Elec. Ill.	Cleveland, O.	456	2.90	1.03	3.93	809	6.27	26.60	11.781	506,000	212,000	290,000

(a) From Federal Power Commission Data.
(b) Assuming 5,000 lbs per pound as fuel value of refuse, and 90 per cent of refuse usable as fuel.
(c) Assuming 4 pounds per capita per day, 365 days per year.

pulverized coal in combination with oil or gas. Although it may be doubtful that the process would be attractive to those plants designed to burn only oil or gas, long-range economic evaluations of specific applications, taking into account the impact upon the solid waste disposal problem of a given community, might show both overall economic and social benefits accruing from oil and gas-fired plants being adapted to permit application of the process.

4. The assumption is made that the boiler plants listed could be modified to burn prepared refuse in suspension. Table No. 21 lists only plants with tangentially-fired furnaces. Should the firing of the material in a tangentially-fired furnace be proven successful, it would appear that there would be a significant incentive for both the utilities and the manufacturers of front-fired and cyclone-fired boiler furnaces to develop the adaptations required for their equipment to be suitable for application of the process.
5. Several of the boiler plants listed in Table No. 21 consumed oil and/or gas in addition to coal during 1967, the period for which the listed data apply. It may be that if prepared refuse were available for these plants, it could also be burned as supplementary fuel with the oil or gas, in addition to coal, thereby permitting the firing of more refuse. In general, the cost per million Btu of oil or gas is higher than for coal. However, when oil or gas is burned, there obviously would be less operation expense required for ash handling than when pulverized coal is burned.
6. The tabulation reflects the assumption that 10 per cent of only the coal burned in 1967 in the boilers could be accommodated by prepared refuse. It of course is possible that this assumption is optimistic. On the other hand, it is possible that greater percentages of refuse could be burned without adverse effects, and with corresponding increased benefits.
7. The population assumed to contribute the amount of prepared refuse equivalent to 10 per cent of the fuel value of coal was computed on the basis of 10 per cent of the raw refuse being removed in the preparation process as being unsuitable for burning, with the additional assumption that refuse production would be about 4.0 pounds per capita per day, 365 days per year. It is possible that more or less than 10 per cent of the raw refuse would be removed in the preparation process, with a corresponding difference in the amount of raw refuse required to produce an equivalent amount of suitable fuel. The assumption that refuse production is 4.0 pounds per capita per day also may vary significantly from one area to another.

8. The calorific value of prepared refuse is assumed to be 5,000 Btu per pound. This assumed value may vary somewhat in various parts of the country.

Even under the preceding limitations, it is apparent that there are many existing boiler plants in which prepared refuse conceivably could be used as supplementary fuel. The fuel costs at the plants in the northeast part of the country are much higher than in the midwest. Two plants in the New York City area, for example, had 1967 fuel costs of \$0.36 to \$0.37 per million Btu, almost double the cost of fuel in the St. Louis-Kansas City area. It should be recognized also that fuel costs are increasing.

The costs of refuse disposal in the northeast part of the country also are high. There certainly would be a substantial economic incentive for both the cities and the utilities in the northeast area to at least explore the possibilities of collaborating in application of the process.

It has been pointed out that for the St. Louis area it would be necessary to transport the prepared refuse some distance to those boiler facilities which appear most likely to be adaptable to the process. In more concentrated metropolitan areas, such as in the northeast part of the country where power plants are located well within the developed parts of the area, the costs of transport could be reduced significantly. For example, if a large-scale processing plant could be constructed within about one mile of a power plant suitable for burning refuse as a supplementary fuel, it is probable that the costs of transport could be reduced by \$0.75 to \$1.50 per ton from the estimated costs developed in this study.

POWER PLANT PRODUCTION COSTS

The twentieth annual supplement (1967) of "Steam-Electric Plant Construction Cost and Annual Production Expenses" published by the Federal Power Commission in November 1968, lists the production expenses for the Meramec Plant as follows:

Total Operation Expenses	0.35 mills/kwh
Total Maintenance Expenses	0.52 mills/kwh
Fuel Costs	<u>2.06 mills/kwh</u>
Total	2.93 mills/kwh

It may be noted that the fuel cost was about 71 per cent of the total production cost. About 2,410,900 tons of coal were burned in 1967, with a reported fuel value of 11,109 Btu per pound. In addition, 3,479.1 million cubic feet of gas were burned, with a fuel value of 1,044 Btu per cubic foot. The cost of coal was reported as 20.82 cents per million Btu and the cost of gas as 22.78 cents per million Btu.

Comparison of the preceding data with those presented in Table No. 21 will show that the total production expenses of the Meramec Plant are in the lower range of the plants listed. It will be apparent that even a small reduction in fuel cost will have a significant effect upon the total production cost. Boilers adaptable to the use of prepared refuse as supplementary fuel therefore have a potential advantage in economy of operation that conceivably could affect the scheduling of operation of existing units as well as the selection of units for new power plants.

IMPACT UPON COMMUNITY REFUSE DISPOSAL

It has been pointed out that approximately 4,000 tons of refuse per day presently is produced in the St. Louis Metropolitan Area and disposed of in public facilities. It is estimated that approximately half of this quantity would be available immediately for processing as supplementary fuel for boiler furnaces in the Union Electric Company system. The potential capability of only the Meramec and Labadie Plants of the Union Electric system is such that these two plants could accommodate essentially all the burnable refuse produced within the metropolitan area.

If only the magnetic metals were removed from the refuse in the processing operation, these magnetic materials, about 5 to 10 per cent by weight of the raw refuse, would require disposal by the processing agency. By way of comparison, sanitary landfill would require 100 per cent of the total refuse to be disposed of, and the residue from a conventional incinerator would be on the order of 25 to 30 per cent by weight of the raw refuse, and would in most cases require sanitary landfill as an acceptable means of disposal. It is obvious that the ultimate disposal of both the burnable and inert fractions of solid waste materials would be appreciably simplified if the proposed process were adopted.

Adoption of the proposed process therefore not only would permit the fuel value of the solid waste materials to be utilized, but would conserve substantially the available volume of landfill sites for materials which could be disposed of by no other acceptable method. Further, it is possible that under favorable circumstances it would be possible for some revenue to be derived from the sale of the magnetic materials. Although it appears unlikely that a significant market would develop within the foreseeable future, mainly because of the tin coatings on cans, it is possible that favorable market conditions for magnetic materials could occur in the future.

The preceding observations, although principally directed toward the situation prevailing in the St. Louis area, would apply to most of the other metropolitan areas in the United States. In the concentrated metropolitan areas in the northeast part of the country, it is quite possible that 70 to 80 per cent of the total refuse produced could be used as supplementary fuel.

IMPACT UPON AIR POLLUTION CONTROL

Most of the modern fossil fuel-fired power plants are equipped with electrostatic precipitators for the removal of particulate matter from the gases of combustion. Although it is believed that the dust loadings in such precipitators possibly could be increased, it also is believed that there probably would be no discernible difference in the chimney emissions if prepared refuse were fired as supplementary fuel to the extent of about 10 per cent of the total fuel requirement.

Conventional refuse incinerators, even when equipped with dust control devices, will discharge some dust to the atmosphere, even though such emissions may be within the limits prescribed by local ordinance. If a substantial portion of the refuse from a given metropolitan area were to be burned as supplementary fuel in large-scale boilers, instead of in conventional incinerators, there obviously would be a net reduction in the particulates discharged to the atmosphere for the area, with a corresponding improvement in ambient air quality.

Refuse contains only a small percentage of sulfur, far less than most coals. Even though the refuse burned in boiler furnaces might be only a fraction of the total fuel burned, there should normally be a slight reduction in the emission of sulfur oxides.

Most of the recent and the most stringent of the air pollution control ordinances and regulations set limits upon the percentage of sulfur in coal. The use of low-sulfur coal normally will have the effect of increasing fuel costs. It is possible that the use of prepared refuse as a supplementary fuel will assist in minimizing such fuel cost increases.

The chlorine content of refuse also is small. There are no known data as to what amounts, if any, of chlorine compounds are contained in the gases resulting from the combustion of refuse. Air pollution control ordinances normally do not set limits for the emission of gases containing chlorine.

Although there presently are no local standards relating to the control of nitrogen oxides, air quality objectives include limits on nitrogen oxides in ambient air. The low excess air requirements for coal-fired boiler plants (estimated to be about 23 per cent when 10 per cent of the fuel is prepared refuse), are far less than those of conventional incinerators, in which the required excess air may be in the range of 100 to 170 per cent.

IMPACT UPON UTILITIES

The economic incentive for a utility to use prepared refuse as supplementary fuel obviously is dependent upon the distribution of costs necessary to make the process attractive to both a municipal corporation and a utility.

Such an incentive could be very attractive in some cases, and in other cases there may be no economic incentive at all.

The discussions included in Part VI of this report generally conclude that although operational problems in large boilers could possibly result in adverse effects, the probabilities are minimal of such adverse effects being significant, as long as the refuse is fired as a relatively small percentage of the total fuel.

Some benefit to at least some utilities could result from improved community relations, by virtue of the utility assisting the community in solving one of its greatest problems. Whether utilities would wish to actually enter the field of refuse disposal, as agencies receiving raw refuse and processing it for their own use, would appear to be a matter of individual policy.

APPLICATION OF PROCESS TO GAS-FIRED POWER PLANTS

This report has been directed toward the use of boilers equipped to burn pulverized coal. Essentially all of the larger power plants in the western and southwestern parts of the country utilize gas as the principal fuel. The cost of gas for these plants is in the range of \$0.29 to \$0.30 per million Btu. Other power production costs for these plants are low, principally because they have no bottom ash or fly ash problems to contend with. It appears doubtful that a utility would wish to modify an existing unit designed for gas firing only to accommodate prepared refuse as a supplementary fuel. Evaluation of the process described in this report as applied to gas-fired boilers is regarded as being beyond the scope of this study. It is conceivable, however, that a specific evaluation of the use of prepared refuse as supplementary fuel in a new gas-fired boiler would show that the savings in fuel could justify the additional capital and operating costs required to accommodate the resulting ash. This might be most applicable in those areas where refuse disposal is a particular problem, and where a sharing of the costs of preparation and transport of prepared refuse could provide significant economic and social advantages both to the utility and to the community.

CONSERVATION OF NATURAL RESOURCES

Despite the increase in the construction of nuclear power plants, and in the use of gas as fuel, coal still continues to be the principal fuel for power production, and its use also is increasing. It is estimated by "Power" magazine (June 1968) that at the then current rate of coal usage, coal supplies will last 760 years. However, from 1965 to 1985, it is estimated that the use of coal will increase about 65 per cent. Any substitution of other material as fuel in the coal-fired boiler plants obviously could be a significant factor in the conservation of coal.

The proposed process provides for the removal of magnetic metal from the refuse. Most of such metal removed would be contaminated, principally by tin, which makes it unacceptable for most steel producing processes. There are, however, some uses to which the recovered metal could be applied. The present market for the contaminated metal apparently is marginal, but even if it were recovered for reuse at no profit to the processing facility, some conservation of iron resources still would be realized.

It is doubtful, at least at the present time, that it would be economical or even reasonable to attempt to recover other materials from refuse under the premises adopted for purposes of this study.

PART X

NECESSARY RELATIONSHIPS BETWEEN A UTILITY AND A MUNICIPAL CORPORATION

RESPONSIBILITIES

The responsibility for providing a safe, sanitary and aesthetically acceptable system for the disposal of the solid wastes produced in a given community certainly rests with the designated public authorities of that community. From this point of view, the process of burning prepared refuse in utility boilers becomes merely an alternate method of refuse disposal. Should the process be adopted and placed in operation, and should some emergency interrupt the process for any reason, the production of refuse by the community will continue, and that material normally scheduled for burning in boiler furnaces would have to be disposed of by other means.

The electric utility, whether publicly or privately owned, has the basic responsibility of furnishing electricity to the community. The use of prepared refuse as fuel, under the premises established for purposes of this report, probably would be adopted only if economically attractive to the utility. The prepared refuse, fired as a percentage of the total fuel, therefore must be regarded as a supplemental fuel, with its use dependent upon its availability. Interruption in the supply of prepared refuse would merely mean that the utility would increase the rate of firing of its principal fuel to accommodate the demand for electricity.

In this case the controlling responsibility clearly is that of the public agency, which must dispose of the solid wastes produced by some acceptable means. Should an agreement be reached between the public agency and the utility on the use of prepared refuse as fuel, both parties obviously will have responsibilities within whatever limits are set forth in the agreement.

It may be concluded that as a general premise, the preparation of refuse as fuel would be the responsibility of the public agency, and that the firing of this material to the boiler furnaces, when the material is available, would be the responsibility of the utility. The responsibility for the transport of the prepared material to the point of use would appear to depend upon the economics of a particular situation, and would require a mutually acceptable arrangement for the establishment of responsibility, or of a division of responsibility.

BENEFITS

There must be benefits accruing to both the public agency and the utility for an agreement to be reached providing for the burning of prepared refuse

as fuel. The principal incentive for a utility realistically must be of an economic nature, although the management of many utilities may be motivated by the desire to assist in the solution to community problems. The main incentive for the public agency also must be economic in nature, with consideration of such side benefits as improved air pollution control, increased life of sites for sanitary landfill, and, more altruistically, the conservation of natural resources.

The greatest overall benefits from the application of the proposed process would either result in all of the burnable material in the raw refuse produced by a community being consumed as supplementary fuel by the utility, or conversely, as much of the burnable fraction being consumed as the utility could handle. In the former case, the quantity of raw refuse produced is fixed by the production of the community, and this production will vary widely on a daily or weekly basis, and to a lesser degree, on a monthly basis. This variation in quantity would require that the rate of firing the material to the boilers would have to vary in accordance with the availability of the material.

For purposes of this study, the nominal rate of firing is considered to be 10 per cent of the total fuel requirement of the boilers. This percentage could be found to be either smaller or greater than the optimum. Whatever the optimum percentage, it would be difficult for a public agency to guarantee a constant rate of delivery of the prepared material to the utility, unless of course the constant rate were to be well below the minimum rate of collection by the public agency. Under this condition, the controlling economic condition would be the permissible rate of feed to the boilers, and the public agency would have to employ other means of disposal of the excess raw refuse.

From a theoretical point of view, any economic advantage resulting from the proposed process, whether on the side of the public agency or the utility, would be of benefit to the community. Recognizing, however, that the management of a utility and the public officials usually must be responsive to different bodies, any economic benefits must be shared in some proportion. The point of division of benefits undoubtedly will vary from one application to another.

SCHEDULING

A base load utility boiler normally is expected to operate continuously, near full load, on a 24-hour day, 7-day per week basis for a year or more without a major interruption for repair or maintenance. Except in the event of an emergency, shutdowns of such facilities are scheduled far in advance, to ensure that other facilities will be available to accommodate the required load during the shutdown periods.

Municipal refuse, although produced seven days per week, normally is collected only five or six days per week, and only during daylight hours. It is considered impractical, as well as unacceptable to the general public, to collect refuse, particularly domestic refuse, on other than an 8-hour day, five or six-day per week schedule.

The difference in the scheduling of the utilities operation with that of municipal refuse collection obviously must be reconciled to permit full achievement of the economic benefits of the process. This can be done to at least a partial degree by providing storage for either the raw refuse or the prepared refuse. If all of the available burnable material could be consumed during a normal five or six-day week by the utility, with the number of days dependent upon collection practices, the scheduling problem would be simplified. Under this premise, the utility would in effect operate without the supplementary fuel on Sundays, and in some cases on Saturdays, when the demand for electricity normally would be less. Recognizing that the capability of the utility boiler facilities often will exceed the quantity of refuse available as supplementary fuel, it would appear appropriate to schedule both the preparation and burning of the refuse only for the normal collection days. This matter would require the achievement of a mutually satisfactory scheduling arrangement before the execution of an agreement concerning the proposed process between the public agency and the utility.

AIR POLLUTION LAWS

The air pollution regulations presently in effect in the St. Louis area specifically state that refuse may not be burned in a facility designed for other fuel. It is believed that the intent of this regulation was to prevent the incineration of raw refuse in facilities unsuitable for that use, and that the possibility of burning prepared refuse in large boilers under controlled conditions was not foreseen at the time the regulations were conceived. However, since this regulation is in effect, it would be necessary to obtain at least a variance from the appropriate air pollution control agency before the process could be applied. Discussion with local air pollution control officials indicates that existing normal administrative procedures would permit full scale testing of the process, and that if the process were proven successful and attractive, consideration would be given to amending the regulations to permit permanent application of the process.

FINANCING

It has been pointed out that any economic benefits accruing from the firing of prepared refuse to utility boilers logically should be divided between the applicable public agency and the utility. It follows that the financing of capital costs of the required processing, transporting and firing facilities also could be divided. Since the total economic benefits

certainly will vary for a given situation, the division of the benefits, and perhaps of the capital costs, would be subject to negotiation.

In some cases it might be appropriate for the public agency to finance and construct all of the required facilities, and to supply the supplementary fuel to the utility at no cost. The other extreme, which may be unlikely, would be for the utility to finance and construct the facilities, and charge the public agency an appropriate fee for refuse disposal. The most likely method of financing, however, appears to be one in which the processing and transporting facilities would be constructed and operated by the public agency, with all modifications within the boiler plant borne by the utility. In this latter case, the division of the economic benefits would be on the basis of a mutually advantageous contractual agreement.

PART XI

PROTOTYPE FACILITIES

GENERAL

The Union Electric Company, which has cooperated fully in the preparation of the study summarized in this report, has indicated concurrence with the conclusions and observations included herein. The extent of the Union Electric Company's concurrence is evidenced by its stated willingness to consider a specific proposal for a full-scale prototype installation applicable to its Unit No. 1 at the Meramec power plant, which has the potential capability of consuming more than 350 tons of prepared refuse per day.

It is the consensus of those who were intimately involved in this study, that a prototype installation on less than a full scale would not provide an adequate means of resolving those matters having bearing upon the technical feasibility of the proposed process. Meramec Unit No. 1, for example, is the smallest unit in the Union Electric Company system of the reheat type. Since the reheaters and the superheaters of a large-scale boiler are the most critical heat exchange surfaces, a prototype installation should, if at all possible, be applied to a boiler unit of the reheat type. Meramec Unit No. 1 also has the potential of requiring less extensive modifications as a prototype than other boiler units in the system.

The scale of a prototype processing plant to fully serve Meramec Unit No. 1 would be far greater than any comparable refuse processing facility, which incorporates shredding, presently in existence in the United States. The mechanical equipment required for application of the process is commercially available, and with reasonable precautions in equipment selection and layout, there is little indication that significant further development of mechanical equipment would be necessary to assure the required production rates and reliability. The principal unresolved questions regarding the process are believed to relate to corrosion potential and bottom ash handling. Neither of these questions can be resolved adequately without full-scale testing on a relatively long-term basis.

It is considered that there would be only moderate risk in proceeding with the construction of full-scale prototype facilities to evaluate the process, and such full-scale testing certainly will be necessary before the process can be accepted fully by both utilities and municipalities. However, the capital cost of a full-scale prototype installation would be substantial, and if less comprehensive testing could be condoned, at least on a temporary basis, it would be possible to effect some savings in initial capital cost of prototype facilities. Each reduction in the scale or scope of prototype facilities will impose further limitations upon the adequacy of the tests, and it must be borne in mind that sooner or later the testing must be sufficient to achieve all of the required objectives.

OBJECTIVES OF PROTOTYPE INSTALLATION

The principal objectives of a prototype for the firing of prepared refuse to utility boilers would include the following:

1. Physical demonstration of the feasibility of suspension firing of prepared refuse to a large boiler.
2. Determination of the optimum percentage of prepared refuse to pulverized coal.
3. Monitoring the effects, if any, upon corrosion and erosion phenomena in boilers.
4. Determination of the effectiveness of existing boiler combustion controls when refuse is fired at a constant rate.
5. Determination of effects upon boiler performance at varying boiler loads.
6. Monitoring the effects upon dust loadings of electrostatic precipitators and auxiliaries.
7. Monitoring the effects upon bottom ash handling, as well as ash quality.
8. Determination of operational characteristics of the processing plant.
9. Monitoring labor, maintenance and utility costs of the processing plant.

Many other details of boiler and processing plant operation also should be monitored. Such matters include evaluation of acceptable particle size of the prepared refuse, effects of moisture content, observations as to carry-over of dust and unburned materials, and slagging effects.

POSSIBLE VARIATIONS IN SCOPE OF PROTOTYPE FACILITIES

Considering only the situation prevailing in the St. Louis area, there appear to be four principal courses of action which might be adopted to further the testing required to prove the proposed process in accordance with the objectives summarized in the preceding paragraph.

1. Full-Scale Prototype. This approach would consist of the construction of preparation, transporting and firing facilities which would accommodate all of the required objectives.

2. Partial Prototype. This approach would include only part of the equipment required for the full-scale prototype, and would consist of the construction of facilities which would permit testing of Meramec Unit No. 1 to a relatively full extent, but which would not permit full evaluation of processing facilities. Construction of a full-scale plant could be completed later.
3. Reduced-Scale Prototype. This installation would consist of processing equipment of sufficient capacity to permit testing of Meramec Unit No. 1 to the nominal extent assumed in this report. Part of the equipment would be reusable for a permanent installation at a later date.
4. Limited Testing Facilities. This approach would consist of the adaptation of an existing City of St. Louis hammermill installation only to the degree necessary to permit intermittent testing of various materials handling units and processes. None of the long-range objectives of the required testing program for a boiler would be achieved.

Each of these four approaches has advantages and disadvantages. Only the full-scale prototype installation would provide an essentially complete resolution of the required objectives. Only the first two would provide installations which could be used for the permanent application of the process. The facilities provided in the third and fourth approaches would be only partially reusable for a permanent application. The third approach would permit resolution of most of the required objectives of a prototype, but on a limited basis. The fourth approach would permit only the intermittent testing of some of the required material handling equipment, and would not permit resolution of any of the questions relating to the potential long-range effects of the process upon boiler operation.

Practical limitations of financing may not permit construction of the most desirable testing facilities, those providing for the full-scale prototype. Each of the four approaches outlined therefore may deserve consideration if a compromise is necessary, and are discussed in the following paragraphs for purposes of comparison.

FULL-SCALE PROTOTYPE (NO. 1)

For the reasons discussed previously, the application of a full-scale prototype for preparing, transporting and firing refuse as supplementary fuel is assumed to be one which will permit evaluation of the process in Meramec Unit No. 1.

Quantity to be Fired According to computations by Combustion Engineering, Inc., the efficiency of the boiler may be lowered slightly by burning prepared refuse as supplementary fuel. However, due to the variations in heat value of both coal and refuse, and the empirical nature of combustion calculations, precise computation of boiler efficiency may be considered to be somewhat academic, and for convenience of reference in this report, the relationship between quantities of coal and refuse are considered on the basis of differences in calorific values.

At full load, Meramec Unit No. 1 will burn about 57.5 tons per hour of pulverized coal with a heating value of 10,700 Btu per pound. It is assumed, for purposes of evaluation, that 10 per cent of the heating value of the coal would be replaced by an equivalent amount of prepared refuse, with an average heating value of 5,000 Btu per pound. This assumption would result in about 12.3 tons per hour of the supplementary fuel being fired at full load.

The assumption that 10 per cent of the total fuel requirement would be satisfied by the supplementary fuel should be recognized as being arbitrary, since there is no prior experience to serve as a guide. The heterogeneous nature of both the physical and chemical properties of raw refuse lead to the conclusion that in order to provide a reasonable guarantee that the 10 per cent requirement may be met, it would be appropriate to provide for a moderate factor of safety in the design of processing and firing facilities. The further assumption therefore is made that the maximum rate of firing for a prototype unit initially would be 15.4 tons per hour of prepared refuse, which would be equivalent to about 12.5 per cent of the required fuel value at full load. Greater percentages could be fired later, depending upon initial findings.

It is recommended by Combustion Engineering, Incorporated, the designers and manufacturers of the boiler serving Meramec Unit No. 1, that one level of the existing gas burners, between the two middle levels of pulverized coal burners, be removed. These would be replaced with four burners for firing prepared refuse, one in each corner. Each of the new burners would have the capability of discharging 6.0 tons of prepared refuse per hour into the furnace through a 6-inch diameter pipe. This modification would not detract from the utilization of any of the existing pulverized coal burners, and according to computations by Combustion Engineering, Incorporated, would still permit full boiler capability to be achieved by the remaining gas burners by raising the gas pressure by about 3.0 psi.

With four 6-inch pipe lines, each capable of discharging 6.0 tons per hour of prepared refuse into the furnace, the total capability thus would be 24 tons per hour, or about 19.5 per cent of the total fuel requirement of the boiler at full load. Although this quantity is greater than the maximum 15.4 ton per hour rate contemplated for an initial demonstration, it is not believed advisable to reduce the pipe size, because of the increased possibilities of blockages.

The installation of the four burners as described, each fed by a 6-inch pipe, therefore is considered to be compatible with the configuration of the boiler furnace and the existing burner settings, and is regarded as being a positive and conservative arrangement to achieve satisfactory operation. This method of installation is particularly significant in that the new burners could be installed without modifications of boiler tubes and with little disruption of boiler operation. It is anticipated that the new burners will have provisions for shut-off gates which will be capable of isolating the refuse firing system from the existing boiler facilities without disrupting continuity of boiler operation.

It is anticipated that the boiler would be operated as a base-load unit even during a period of demonstration, so that it would be operating essentially at a constant rate and at or near its full capability. The only exception to this mode of operation would be to investigate performance of the boiler during partial loadings. It appears doubtful that even under this latter condition that the boiler would be permitted to operate at less than 50 per cent of its rated load.

Quantity of Refuse to be Processed. The nominal anticipated maximum firing rate of the prepared refuse, 15 4 tons per hour at full load, is equivalent to 370 tons of prepared refuse per day. The quantity of raw refuse requiring processing will be greater than 370 tons per day, since certain fractions of the raw refuse are intended to be removed from the material to be fired. It has been pointed out that most of the magnetic materials can be expected to be removed relatively easily by means of magnetic separators. The limited tests described in Part III of this report have indicated that between 5 and 10 per cent by weight of the raw refuse will be magnetic metal. This range is substantiated by the data presented in Tables 2, 3 and 4. Assuming removal of only the magnetic metal, the total quantity of raw refuse requiring processing would be on the order of 390 to 410 tons per day. The higher value, 410 tons per day, is deemed appropriate for purposes of this study.

In Part VII of this report, it was concluded that the potential benefits to be gained by the removal of glass and ceramic particles probably would not be sufficient to justify the additional capital and operating costs of screening facilities. No further consideration is given, therefore, to the inclusion of screens in a prototype unit.

The physical size of the mills and conveyors required to handle raw refuse are controlled to a significant degree by the sizes and shapes of the objects comprising raw refuse. It appears doubtful that economies of more than a minor nature would be effected by attempting to refine sizes and capacities of the processing equipment to too great a degree. The single processing unit described in Part VII of this report would have a nominal average capacity of 70 tons per hour. Since deliveries of refuse by City of St. Louis vehicles normally take place over a 6-hour period,

and since it would be desirable to operate a prototype processing facility only one shift per day, the single processing unit described in Part VII of this report is considered to be of the approximate size and capacity required to accommodate the prototype. The estimated capital costs presented herein reflect this conclusion.

Quantity of Refuse Available for Processing. The quantity of refuse available from City of St. Louis collection vehicles in 1968 averaged about 4,490 tons per week, with collections normally made on a five-day per week basis. Maximum and minimum weekly collections were about 25 per cent above and below the average. At a nominal rate of 410 tons per day for the raw refuse to be processed, the City of St. Louis refuse collections will be adequate to supply the processing demands, since the average daily quantity collected in the minimum week of 1968 was about 670 tons. With appropriate scheduling of collection trucks to deliver refuse to the processing plant, there should be a more than adequate raw refuse supply. It is anticipated that at times a few of the City collection vehicles may be required to alter their collection routes and schedules to accommodate the needs of the prototype processing plant.

Availability of Facilities at Power Plant. If a prototype for firing prepared refuse were applied to Meramec Unit No. 1, the testing would be required to be conducted at a time and under conditions which would be fully acceptable to the Union Electric Company. Under the conditions expected to prevail for at least the next several years, it appears probable that Meramec Unit No. 1 will be required as a major power source during the summer months when the demand for electricity is greatest. There appears to be some doubt that this unit would be made available for testing during such periods unless there were positive assurance of the tests being successful. The unit may therefore be available for initial testing only during the months of, say, October through April. The anticipated arrangement for firing the prepared refuse would permit the firing to be interrupted without interference with boiler operation, however, and if no significant operational problems were to be encountered during initial tests, the Union Electric Company conceivably could elect to continue testing during the summer months.

Practical considerations may limit testing to no more than a portion of a calendar week at one time. The collection of refuse by City of St. Louis vehicles normally is confined to a five-day week. Unless provisions were made for the storage of the equivalent of two day's supply of raw or processed refuse, the present collection schedules would not permit processing on a seven-day basis, although it would be possible with proper scheduling, and with provisions for additional equipment, to process the material six days per week. It appears likely that frequent examinations of the boiler and its auxiliaries would be desirable during a test period, in order to assess any adverse effects. From the standpoint of the Union Electric Company, it is understood such examinations can best be scheduled during the normal five-day work week. It appears probable, therefore, that the firing of prepared refuse for testing would be most appropriately scheduled on a five-day week basis, with processing performed to suit the schedule of required refuse deliveries to the boiler plant.

Location of Processing Facilities It is regarded as important that a prototype processing facility be located near an existing refuse disposal site, to permit convenient disposal of refuse should the operation of the prototype be interrupted. In this case the site of the prototype processing facility is considered adjacent to the existing South Incinerator of the City of St. Louis, which is about 18 miles from the Meramec Power Plant.

Prototype Processing Facilities The processing facilities required for a full-scale prototype installation are assumed to be essentially the same as those described for a single processing unit in Part VII of this report. These facilities would not interfere with the operation of the existing incinerator.

Transport Facilities Assuming the truck-trailer units would haul about 20.5 tons per load, about 18 trips per day, or 6 trips per 8-hour shift, will be necessary to haul 370 tons of supplementary fuel from the processing plant to the power plant. The transporting facilities are considered to be comprised of:

1. Two 30,000 cubic foot storage silos for milled refuse, located at the processing plant, and equipped with live bottoms and conveyors to discharge to a stationary packer.
2. One stationary packer to load transport trailers.
3. Three 75 to 80 cubic yard tractor-trailer units for hauling prepared refuse from the processing plant to the boiler plant. One of the three units would be a spare.

Receiving Facilities at Power Plant In order to minimize interference with operations at the Meramec Plant, it appears appropriate to locate the facilities required to receive the truckloads of processed material at some point outside of the plant proper, yet in close enough proximity to permit pneumatic conveying of the material to a short-term storage facility near the point of use. The site which has been assumed for the receiving station is near the plant entrance roadway, several hundred feet from Unit No. 1.

The self-unloading trailers would discharge into a steel hopper set in a concrete pit. The hopper would have sufficient capacity to accommodate at least one truckload of the prepared refuse. It would be equipped with a triple screw conveyor in the bottom to effect discharge of the material into a rotary air lock feeder, which would introduce the material into a pressurized pneumatic pipeline. A positive displacement type blower would provide the transporting air within the pipeline to a short-term storage silo located near Unit No. 1. All of the equipment at the receiving station would be enclosed in a building, including the truck dumping facilities. A diagram of the receiving station is shown on Figure 5. Unloading of the trucks would be performed by the truck drivers, who would merely be required to

activate the unloading mechanisms on the trailers. Controls would be provided to ensure that the pneumatic system would not convey the material to the storage silo unless there were sufficient volume available in the silo to receive it.

Storage and Firing Facilities. The short-term storage silo, the pneumatic system and other equipment required to feed the prepared refuse to a boiler should be in relatively close proximity to the boiler. This is necessary, not only to minimize the power requirements of the pneumatic feeding systems, but to permit close supervision and control of the operation of the equipment and of the relative quantities of prepared refuse fired as fuel.

Considering the space available at the Meramec Plant for the equipment required for storage and firing, there are two locations which conceivably would be suitable. One location is inside the boiler plant building, a vacant bay between Units No. 1 and No. 2. This location would provide the greatest operational convenience, and should the prototype for Unit No. 1 prove successful, the process could also be applied to Unit No. 2, with relatively minor modifications, as a permanent installation. A preliminary structural analysis by Union Electric Company personnel has indicated that the building superstructure and foundations are adequate to accommodate the required loadings. Consideration also might be given to the installation of this equipment outside the building. One such location would be about 250 feet directly to the rear of Unit No. 1. This location would not interfere with any of the normal plant operations, but of course would be less convenient for coordinating the firing of prepared refuse with pulverized coal. For purposes of this report, the refuse storage and firing equipment will be considered to be located in the vacant bay between Units No. 1 and No. 2.

The method of firing the supplementary fuel to Meramec Unit No. 1 deemed most applicable is a high pressure pneumatic system, which utilizes a positive displacement type blower to discharge through a pipeline at a pressure of several psi. The prepared material is introduced into the pressurized pipeline through a rotary air lock feeder. The rotary feeder would be required to pass all materials contained in the prepared refuse, including metal particles not removed in the processing facilities.

As previously stated, Combustion Engineering, Incorporated, recommends that four burners for firing the prepared refuse be installed in the corners of the furnace of Meramec Unit No. 1. A separate blower and feeder would be required for each of the four burners.

The minimum facilities required to accommodate the desired quantity of prepared refuse from the receiving station to the boiler are considered to be as follows:

1. A pneumatic pipeline from the blower at the receiving station to a storage silo.

2. One short term storage silo with about 6,000 cubic feet capacity, 20 feet in diameter by 20 feet high, equipped with a live bottom.
3. Dust control equipment for the silo.
4. One conveyor equipped with a weighing device to control the rate of feed.
5. One vibrating distributor to serve as a means of dividing the refuse equally to four feeders.
6. Four heavy-duty rotary air lock feeders, one for each of the burners to fire prepared refuse, each capable of feeding up to 6.0 tons per hour of prepared refuse.
7. Four positive displacement type blowers, equipped with intake silencers, each capable of supplying conveying air for the material to be handled by the rotary feeders.
8. Replacement of one level of gas burners in Unit No. 1 with burners suitable for firing prepared refuse.
9. All necessary pneumatic piping from the blowers to each of the new nozzles for firing prepared refuse.
10. All necessary electrical wiring, interlocks and controls for the blowers, feeders and other electrically powered equipment.

PARTIAL PROTOTYPE (NO. 2)

The full-scale prototype processing plant is considered to include two-stage milling, together with the required auxiliary equipment, to process about 70 tons per hour of refuse. The partial prototype processing plant as conceived herein would provide for single-stage milling, with a processing rate of about 40 tons per hour. This rate would permit about 320 tons of raw refuse to be processed in a nominal 8-hour working shift, and would, under these conditions, provide an average boiler feed rate of about 12.3 tons per hour. To achieve greater feed rates, the partial processing plant would have to operate more than 8 hours per day.

As in the case of the full-scale prototype, the partial prototype processing plant would be constructed at the site of the existing south City of St. Louis Incinerator. The partial prototype facilities would be installed so as to be essentially reusable in place as part of a future full-scale processing plant.

The processing plant would consist of a single live-bottom receiving pit, a single-stage hammermill, a magnetic separator, and those conveyors

and auxiliary equipment necessary to convey the prepared refuse to a short-term storage silo. The required transport facilities would include a single storage silo, a stationary packer and two transfer tractors and trailers. The receiving and firing facilities at the power plant would be the same as for the full-scale prototype.

REDUCED-SCALE PROTOTYPE (NO 3)

As a means of further reducing the capital cost of prototype processing facilities, it would be possible to effect economy by reducing the processing rate and by providing less elaborate equipment for handling the raw refuse. A single-stage hammermill, of 35 to 40 tons per hour capacity, operating 8 to 10 hours per day, would process sufficient refuse to permit a 12.3 ton per hour continuous firing rate in Meramec Unit No. 1, approximately equivalent to 10 per cent of its fuel requirement at full load.

The facilities required for this installation would include a feed conveyor, which would be served by front-end loaders from a flat storage area for the raw refuse, a 40 ton per hour hammermill, a discharge conveyor equipped with a magnetic separator, and a pneumatic system for conveying the milled refuse to a short-term storage silo. The transport facilities, and the facilities required at the power plant for receiving and firing the milled material, would be the same as for the Partial Prototype installation.

LIMITED TESTING FACILITIES (NO 4)

Under Demonstration Project No. 115, of the United States Public Health Service, the City of St. Louis has constructed facilities for the size reduction of logs and waste wood, and of bulky refuse items. These facilities include a hammermill with an inlet opening of about 4 feet by 5 feet, driven by an 800 horsepower motor. The mill is equipped with feed and discharge conveyors.

It appears conceivable that the existing hammermill facilities could, with coordinated scheduling, be used for preparing refuse as supplementary fuel, on an intermittent batch basis, as well as for the purposes originally intended. The grate bars of the mill would have to be changed to achieve smaller particle sizes of the milled material.

A magnetic separator would be installed over the discharge conveyor from the mill. This would permit preparation of the refuse to the degree deemed necessary for firing to boiler furnaces.

From the discharge conveyor of the mill, after removal of magnetic metals, the milled refuse would be discharged to an existing City-owned packer-type truck, which would be used for transporting the supplementary

fuel to the power plant. It is anticipated that compaction tests can be made in this vehicle, as well as observations of the behavior of the milled material during transport.

The packer-type truck would deliver the milled refuse to the site of the boiler unit (Meramec Unit No. 1), at which point the truck would discharge the refuse to a live-bottom receiving bin. This procedure will permit assessment of the receiving facilities on a scale comparable to that of a full-scale prototype.

The live-bottom receiving bin would discharge the milled refuse to a hopper which would serve as the inlet to a rotary air-lock feeder. This feeder would introduce the milled refuse into a pressurized pneumatic pipeline. The pressure of the pneumatic system would be provided by a positive displacement-type blower. The capacity of the pneumatic system would be such that the milled refuse could be transported at a rate of about 6.0 tons per hour, to match the maximum anticipated rate for one burner at Meramec Unit No. 1. The pneumatic system would be arranged to permit discharge to either a storage silo or directly to the boiler furnace, by means of a diversion valve.

The storage silo would be equipped with a live-bottom to permit tests of the capability of the equipment to ensure a reasonably uniform rate of feed from the silo. The silo also would be equipped with air-solids separation devices for the control of dust resulting from the pneumatic operation.

The direct discharge from the pneumatic system to the boiler furnace would be through a single nozzle installed in one corner of the furnace. This would permit observation of the distribution pattern of the refuse blown into the furnace, and of the general pattern of combustion of the particles of refuse. It is anticipated that some knowledge also may be gained as to what proportion of the milled refuse would fall to the bottom ash hopper without undergoing complete combustion.

It will be noted that only limited testing could be performed with this approach. The processing of the refuse would be intermittent, and the most critical aspects of the required testing, those related to boiler operation, could not be resolved.

ESTIMATED COSTS OF PROTOTYPE FACILITIES

The estimated capital costs of the four forms of prototype facilities discussed in the preceding paragraphs are summarized in Table No. 22. For purposes of comparison, the costs are all escalated to those anticipated in 1971.

TABLE NO. 22

ESTIMATED CAPITAL COSTS
PROTOTYPE FACILITIES

	Full-Scale Prototype No. 1	Partial Prototype No. 2	Reduced-Scale Prototype No. 3	Limited Testing Facilities No. 4
<u>Preparation Facilities</u>				
Site Preparation and Roadways	\$ 23,000	\$ 23,000	\$ 10,000	-
Building and Structures	770,000	630,000	170,000	-
Equipment, Mechanical and Elec.	1,340,000	822,000	620,000	\$ 21,000
Subtotal	\$2,133,000	\$1,475,000	\$ 800,000	\$ 21,000
Construction Contingencies	213,000	148,000	80,000	4,000
Engineering, Administration and Supervision	192,000	132,000	80,000	4,000
1969 Estimated Cost	\$2,538,000	\$1,755,000	\$ 960,000	\$ 29,000
Escalation to 1971	261,000	175,000	100,000	6,000
Total 1971 Estimated Cost	\$2,799,000	\$1,930,000	\$1,060,000	\$ 35,000
<u>Transportation Facilities</u>				
Structures	\$ 20,000	\$ 13,000	\$ 13,000	-
Equipment, Mechanical and Elec.	117,000	62,000	64,000	-
Subtotal	\$ 137,000	\$ 75,000	\$ 77,000	-
Construction Contingencies	13,700	7,500	7,500	-
Engineering, Administration and Supervision	12,300	6,500	6,500	-
1969 Estimated Cost	\$ 163,000	\$ 89,000	\$ 91,000	-
Transfer Tractors and Trailers	105,000	70,000	70,000	-
Total 1969 Project Cost	\$ 268,000	\$ 159,000	\$ 161,000	-
Escalation to 1971	28,000	16,000	16,000	-
Total 1971 Estimated Cost	\$ 296,000	\$ 175,000	\$ 177,000	-
<u>Receiving Facilities</u>				
Site Preparation and Roadways	\$ 5,000	\$ 5,000	\$ 5,000	-
Building and Structures	63,000	63,000	63,000	\$ 21,000
Equipment, Mechanical and Elec.	87,000	87,000	87,000	10,000
Subtotal	\$ 155,000	\$ 155,000	\$ 155,000	\$ 31,000
Construction Contingencies	15,500	15,500	15,500	4,000
Engineering, Administration and Supervision	14,000	14,000	14,000	6,000
1969 Estimated Construction Cost	\$ 184,500	\$ 184,500	\$ 184,500	\$ 41,000
Escalation to 1971	19,500	19,500	19,500	9,000
Total 1971 Construction Cost	\$ 204,000	\$ 204,000	\$ 204,000	\$ 50,000
<u>Firing Facilities</u>				
Structural Modifications	\$ 40,000	\$ 40,000	\$ 40,000	\$ 10,000
Electrical and Mechanical Modifications	5,000	5,000	5,000	5,000
Boiler Modifications	20,000	20,000	20,000	6,000
Equipment, Mechanical and Elec.	186,000	186,000	186,000	71,500
Subtotal	\$ 251,000	\$ 251,000	\$ 251,000	\$ 92,500
Construction Contingencies	25,000	25,000	25,000	9,500
Engineering, Administration and Supervision	23,000	23,000	23,000	10,000
1969 Estimated Construction Cost	\$ 299,000	\$ 299,000	\$ 299,000	\$112,000
Escalation to 1971	31,000	31,000	31,000	12,000
Total 1971 Estimated Cost	\$ 330,000	\$ 330,000	\$ 330,000	\$124,000
TOTAL ESTIMATED CAPITAL REQUIREMENTS	\$3,629,000	\$2,639,000	\$1,711,000	\$209,000

COMPARISON OF EFFECTIVENESS OF PROTOTYPES

The principal factors having bearing upon the relative effectiveness of the four forms of prototype facilities are compared in Table No. 23. It is apparent from the comparisons that essentially no value would accrue from construction of the limited testing facilities, and that only partial value would result from the reduced-scale prototype. The most complete resolution of the critical areas of investigation obviously would be accommodated by the full-scale prototype. The principal disadvantage of the partial prototype would be that only partial information would be gained relating to processing operations and costs.

TABLE NO. 23

COMPARISON OF OBJECTIVES AND FACTORS TO BE CONSIDERED
FOR PROTOTYPE FACILITIES

Comparison Factors	Full-Scale Prototype	Partial Prototype	Reduced-Scale Prototype	Limited Testing Facilities
	No. 1	No. 2	No. 3	No. 4
1. Capital Cost	High	Moderately High	Moderately Low	Low
2. Potential for Permanent Use	Good	Good	Partial	Partial
3. Firing Feasibility	Good	Good	Good	Partial
4. Optimum Per Cent of Refuse	Good	Good	Limited *	Poor
5. Corrosion and Erosion Effects	Good	Good	Limited *	None
6. Boiler Combustion Controls	Good	Good	Limited *	None
7. Varying Boiler Loads	Good	Good	Limited *	None
8. Dust Loading Effects	Good	Good	Limited *	None
9. Bottom Ash Handling	Good	Good	Limited *	None
10. Processing Operations	Good	Partial	Partial	Poor
11. Processing Costs	Good	Partial	Partial	None

* Limited to 10 to 15 per cent of boiler fuel requirement.

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APPENDIX

COMBUSTION ENGINEERING, INC.
RESEARCH AND PRODUCT DEVELOPMENT

MIXED REFUSE BURNING
MERAMEC NO. 1
CONTRACT 11049
UNION ELECTRIC COMPANY
CITY OF ST. LOUIS, MISSOURI
HORNER & SHIFRIN, CONSULTING ENGINEERS

April 10, 1969

OBJECTIVE:

1. Evaluate overall unit performance when firing 10% refuse and 90% coal heat input, and recommend modifications to the boiler necessary in order to fire the refuse.
2. Discuss potential for boiler corrosion when firing coal and refuse compared to firing coal solely.

ABSTRACT

Disposing of municipal refuse is becoming a more serious problem every year, because collection and disposal costs are increasing, and available land-fill sites are rapidly being saturated. Incineration reduces the volume of refuse to approximately one-tenth its original volume, but it increases disposal costs. Furthermore, most incinerators in use do not comply with air pollution control ordinances currently being put into effect.

Early in 1968 Horner & Shifrin, Inc., consultants to the City of St. Louis, and Union Electric Company began evaluating the possibilities of burning refuse in an existing coal fired steam generator. Meramec Station Unit No. 1 was selected for the study and Combustion Engineering was asked to give an opinion on the expected effect on the unit's performance. The preliminary evaluation indicated the project had good potential for disposing of municipal refuse with minimum pollution and efficient utilization of its heating value. This could result in fuel cost savings to the utility and provide an economical means of disposing of refuse for the city.

As presently planned, the refuse would be prepared by grinding and magnetic separation and then fed to each corner of the boiler through pneumatic feed pipes, at a rate of approximately 10% of the total heat fired. Therefore, necessary burner modifications and a summary of the expected performance of the unit must now be evaluated to further determine the project's feasibility.

CONCLUSION

Meramec Unit No. 1 could be converted for the process at a very reasonable cost, as burner modifications to burn 10% refuse would be relatively simple. The only other new equipment required would be the refuse preparation and handling system. Furnace performance would be virtually unchanged except for an increase in total ash generated.

No significant change in corrosion, erosion, slagging or general operating procedures is expected. Actual deposit formation, slagging, and corrosion would be determined by installing test probes at various locations in the boiler.

MECHANICAL DESIGN

This report recommends modifications to the boiler to burn prepared municipal refuse in Meramec Station, Unit No. 1 (Contract 11049), which is a 125 MW coal fired, natural circulation unit with a steam capacity of 925,000 lb/hr. The design conditions described are for a refuse heat input equivalent to 10% of the design heat input of the unit, approximately 124×10^6 Btu/hr. The system would be capable of 19.4% heat input, as described in Mr. J. Mullen's letter of March 14, 1969 to Horner & Shifrin (Attachment #1).

Refuse would be pneumatically transported to the boiler burner wind-boxes by four pipes, one to each corner. The only modifications considered necessary are in the burners and the feed piping, and these are discussed below. Carryover of unburned refuse particles out of the furnace is possible, but not expected, and there would be no increase in erosion. Heavy moist refuse particles might fall to the furnace bottom before they burn completely. Air and gas weights would be very close to the original design conditions, as shown on the attached tabulation. Therefore, the present forced draft fans and induced draft fans would be adequate. The increase in gas and air weights results from the difference in coals. The refuse tends to reduce both of these quantities, because it requires only 83% as much stoichiometric dry air per million Btu fired.

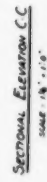
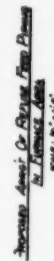
A proposed burner modification based on preliminary evaluations is shown on the attached conceptual drawing NE-694045. The level of gas nozzles above the second level of coal nozzles would be replaced by refuse nozzles, and the other nozzles within the same compartment would be disconnected from the tilt mechanism and fixed in the horizontal position. All other burner compartments would be capable of the full tilt range. This level was selected based on access to the windboxes and optimum burning conditions for the refuse.

The pneumatic feed piping is 6-5/8" O.D. x .188" awt steel dredge pipe, and all bends would preferably be on a 6 foot radius. Air velocity in the feed pipes would be approximately 120 ft/sec., while particle velocity would be only about 30 ft/sec. because the particles are pulled along by drag forces. The air velocity in the nozzle would be about 40 ft/sec. and the particles will have decelerated to about 30 ft/sec. at the nozzle tip.

Location of the refuse nozzle is based on being able to continue to operate the unit at full load with the refuse system shut down. If a level of coal burners were replaced by the refuse nozzles, one mill would be eliminated and the other three would have to operate at peak capacity to carry full load. If one of these three had to be shut down, load would have to be reduced to about 65%. However, the replacement of one level of gas burners leaves 83% of the gas burners available for full load gas firing. An increase of about three psi in gas pressure would supply enough gas for full load.

The fuel analyses used represent averages, and actual operating conditions could vary considerably, especially for the refuse analysis. It should be noted that the higher ash percentage and lower heating value of the refuse used in this study would produce approximately a 15% increase in total ash generated with the 10% refuse heat input.

Based on the above discussion, it is felt this project is feasible from a mechanical standpoint. The recommended modifications could be made at relatively low cost, especially when the great potential for refuse disposal and fuel saving is considered. Furthermore, there would be no loss in availability of the unit because of startup or operational problems with the refuse system.



PROPOSED BURNER MODIFICATIONS & FEED PIPING ARRGT FOR REFUSE FIRING
UNION ELECTRIC CO. OF MISSOURI, MERAMEC POWER PLANT UNIT #1

UNION ELECTRIC COMPANY
MERAMEC STATION UNIT NO. 1
PREDICTED PERFORMANCE

	<u>Coal-1949 Predicted</u>	<u>90% Coal* 10% Refuse</u>
Main Steam Flow - lb/hr	925,000	925,000
SH Outlet Temperature - °F	950	950
SH Outlet Pressure - psig	1400	1400
Fuel Fired - Coal - 10 ⁶ BTU/hr	1238	1131
Refuse		126
Gas Flow Lvg. Econ - lb/hr	1,250,000	1,292,000
Air Flow Lvg. FD Fan - lb/hr	1,158,000	1,183,000
Excess Air - %	22	23
Efficiency - %	88.1	86.7

FUEL ANALYSES

	<u>Average 1949 Coal</u>	<u>Average* 1968 Coal</u>	<u>Prepared Refuse*</u>	<u>90-10 Mixture*</u>
Carbon	60.2	63.0	29.0	56.8
Hydrogen	4.1	4.6	4.1	4.5
Sulfur	2.5	3.2	0.34	2.7
Nitrogen	1.1	1.0	0.4	0.9
Oxygen	7.4	8.4	21.0	10.7
Ash	13.2	8.9	15.4	10.1
Moisture	11.5	10.9	29.3	14.3
HHV - Btu/lb	10,690	11,070	5000	9960

*Coal analysis is average of two coals in February, 1968
Refuse analysis is only typical for a U.S. city. Considerable variations are to be expected.

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COMBUSTION ENGINEERING, INC.

WINDSOR, CONNECTICUT 06095

March 14, 1969

Horner & Shifrin Consulting Engineers
5200 Oakland Avenue
St. Louis, Missouri 63110

Attention: Mr. F. E. Wisely

Re: Mixed Refuse Burning -
Union Electric & City of St. Louis

Gentlemen:

This will confirm our phone conversation this date relative to the firing of prepared municipal refuse in the Meramec Station of Union Electric.

1. Initially, we anticipate firing prepared municipal refuse from four (4) corners at a rate equivalent to 10% of the design heat input of the unit (approximately 124 million BTU/Hr.)
2. Each pneumatic system will have a capability of transporting 12,000 Lbs/Hr. and the total capacity of four systems will be equivalent to about 19.4% of the design heat input.
3. At the initial firing rate of 10% of heat input (24,600 Lbs/Hr. of 5,000 BTU/Lb. refuse), the pneumatic system will be operating at 51% of rated capacity.
4. In the event one pneumatic system is temporarily out of service, the remaining three will have adequate capacity to maintain the desired total flow rate.
5. From the above, it appears that the preparation and handling equipment should be designed for, say, 15% of heat input or 36,900 lbs per hour of prepared refuse. At this rating, each pneumatic system will operate at 77% of capacity. This information is shown on the attached tabulation.

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Mr. F. E. Wisely

-2-

March 14, 1969

We are looking at the refuse entry to the furnace through the middle gas burner compartment. It appears we can remove one row of gas burners for this purpose. Investigation is now being conducted as to the rating the remaining 28 gas burners can maintain. We do not, at this time, anticipate alteration of the coal burners or compartments. The refuse nozzles, however, will remain fixed while the remaining coal and gas nozzles will be capable of tilt control. Further investigation will confirm this.

I trust this will give you the answers you require at this time for your study.

Very truly yours,

COMBUSTION ENGINEERING, INC.

Joseph F. Mullen
Joseph F. Mullen
Industrial Equipment

JFM/jr

cc: Mr. J. J. Carney
St. Louis

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UNION ELECTRIC

PNEUMATIC SYSTEM CAPACITY

	6 T/Hr.	12,000 #/Hr.
Line Size		6-5/8 O.D.
Blower Volume		1,530 CFM
Blower Head		2.97 PSI
Line Length (Estimated)	Horizontal	300 Ft.
	Vertical	30 Ft.
	Bends	450°
Blower H.P. (Installed)		30
(Operating)		24.3 BHP.
Line Velocity (Clean Air)		120 Ft/Sec.
Air Weight (STP)		6,900 Lbs/Hr.
Material - Hogged & Shredded		
Refuse		1"-1-1/2" Max. Size
Bulk Density		4-11 Lbs/F ³
Initial Furnace Heat Input - 10% of Rating	- 124 x 10 ⁶ BTU/Hr.	
Refuse Rate @ 5,000 BTU/Hr. (Total)	24,600 Lbs/Hr.	
	Each System	6,100 Lbs/Hr.
% of Pneumatic System Capacity		51%
Conveying System Capability BTU/Hr.		240 x 10 ⁶
BTU - - % of Furnace Input		19.4%
Preparation Equipment @ 15% of Furnace Input	= 186 x 10 ⁶ BTU/Hr.	
Refuse Rate @ 5,000 BTU/Lb	36,900 Lbs/Hr.	
Conveying System % of Capability		77%

CORROSION POTENTIAL

A literature survey coupled with CE experience in corrosion leads to the following conclusions:

1. Firing a small percentage of prepared refuse with pulverized coal is generally not expected to cause a significant change in corrosion, erosion, slagging or general operating procedures in the boiler.
2. As part of a proposed test program involving mixed refuse burning, the potential of deposit formation slagging and/or corrosion should be determined by probe studies. Controlled temperature probes located in areas potentially subject to wastage and operated over the expected operating range of tube surfaces in the area will yield more data in a shorter period than any other corrosion evaluation procedure.

Corrosion might be expected in three areas as a result of normal operation of utility boilers. Wastage has occurred a) in the high temperature superheater and reheater sections and b) on waterwalls near the firing zone and c) in the low temperature gas passes and air heaters.

Discussion

The potential of increased corrosion due to burning a limited amount of selected refuse in a coal-fired utility boiler can only be finally determined by a test program. The above conclusions are based on the experience of Combustion Engineering with fireside corrosion by conventional fuels, the experience of our licensees in refuse burning for power generation and a review of existing literature.

In order to estimate the corrosion potential of this mixture the analysis of both the refuse and its ash was studied and compared with similar analyses of known corrosive coals.

For the initial program it has been indicated that about 10% of the conventional fuel would be replaced with refuse. Since the average heating value of refuse is about half that for coal, substitution of the equivalent of 10% of the coal would result in about an 18% refuse-coal mixture being used as fuel.

A. High Temperature Corrosion

Samples of St. Louis refuse collected during April and May, 1969 and prepared by Horner and Shifrin were analyzed (Table 1) and the data used in estimating corrosion potential for the mixed refuse burning project. Mixtures of composite Meramec coal and refuse from each of the three collection days were made with 10% of the coal replaced with refuse on a heating value basis.

Ash composition and acid-soluble alkali were determined on each of the samples. These data permit an evaluation of the corrosion potential for each coal by utilizing a Nomograph that correlates the interrelationships of alkalies (sodium and potassium) iron and alkaline earths (calcium and magnesium).

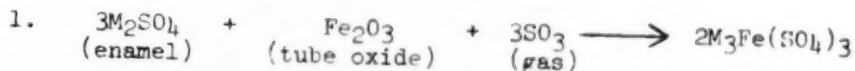
The Nomograph was developed in an extensive research program conducted at Combustion Engineering for the Office of Coal Research. (OCR R&D report No. 41 - page I-3)

All mixtures were 82% Composite Meramec Coal and 18% refuse and constituents reported on a coal basis.

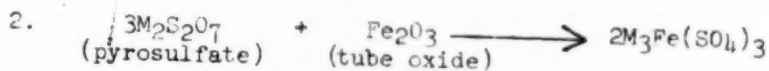
The corrosion index was estimated for each mixture (Table 2). By comparison with a similar estimate using an ash for coal currently burned at Meramec, the mixed fuel indicates only slightly more corrosion potential. Historically the Meramec units have not been subject to corrosion, however, some erosion of steam generating surfaces has previously resulted in installation of shields or wear plates in appropriate areas.

B. Waterwall Wastage

In the 1940's waterwall-tube thinning was found to be the result of chemical reaction between the normal oxide on the tubes, alkali-metal sulfates comprising the enamel deposits on the tube and SO_3 in the furnace atmosphere in contact with the deposits. Two fundamental reactions have been postulated to explain the corrosion.



The second type is observed when the tube deposit contains a sufficiently high ratio of potassium to sodium sulfate to result in a molten phase. In this case SO_3 reacts directly with the sulfate mixture to form pyrosulfate which attacks the oxide



at a higher rate than the dry reaction (1).

The melting point of a mixed alkali pyrosulfate ($\text{K}_{1.5}\text{Na}_{0.5}\text{S}_2\text{O}_7$) is 535F when SO_3 is above 7 ppm. The melting points of several sulfates which may be present in various boiler deposits is shown in Fig. 1. The low melting pyrosulfates are shown as well as the complex sulfates are considered primary agents in superheater corrosion as was previously noted.

In general, waterwall corrosion (tube metal 500-800°F) is associated with external deposits and also with flame impingement. Adherence to proper operating techniques has reduced the concentration of pyrites and SO_3 near the walls, and waterwall wastage is infrequent in normal coal firing. These techniques include a) maintenance of burners to avoid excessive flame impingement b) close attention to coal fineness to prevent coarse coal from reaching the furnace c) maintenance of the distribution in coal feeding systems and d) good air distribution.

Refuse contains considerably less sulfur (0.1-1%) than coal and there is no obvious reason why mixed fuel firing should alter the situation with regard to this type of corrosion.

The prepared refuse from St. Louis contained less than 0.2% chloride (Table 1). It is possible that the presence of chlorine or chlorides from incineration of vinyl plastics as well as the presence of some heavy metal oxides not normally observed in coal ash could affect waterwall wastage.

C. Low Temperature Corrosion

The greater part of the sulfur released in combustion appears in flue gas as SO_2 but a small percentage is oxidized to SO_3 which in the cooler flue gas in the back passes or airheaters reacts with water to form sulfuric acid. If its temperature is below the dew-point, the sulfuric acid condenses on metal and corrosion results (Fig. 2). This type of wastage is usually eliminated by maintaining metal and gas temperatures above the dewpoint and/or by reduction or elimination of SO_3 in the flue gas.

Since the refuse is a low sulfur fuel, mixed fuel firing would be expected to contribute to some reduction of SO_3 and SO_2 in the flue gas.

D. Slagging and Erosion

During the July 8 meeting at the Union Electric Office in St. Louis some concern was voiced regarding the effect of the approximately 5% Na_2O on the slagging characteristics of the ash.

Ash fusions were determined on 82-18 mixtures of composite Meramec coal and refuse from each of the three collection days. The mixtures had 10% of the coal replaced with refuse on a heating value basis. As can be seen from Table 1, there is only a slight decrease in ash fusion temperature of the mixture as compared with the coal ash alone. Slagging tendency is not expected to differ when firing the mixed refuse. Previous testing shows that slagging can be controlled and SO_2 emission reduced by use of alkaline earth additives.

Only actual operation with the mixed fuel will show the full effects of such firing.

The dust loading would be increased slightly with the firing of the expected mixture, and erosion might be increased by virtue of this fact. There is not, however, a sufficient difference between the nature of the refuse fly ash and ordinary coal fly ash to indicate increased abrasiveness.

Evaluation of Potential Wastage

For a test program, probes would be located in the three areas of the boiler where corrosion might be anticipated, in order to allow periodic inspection and evaluation of any wastage. Probes have been chosen as the best method of evaluation because temperature and time of exposure can be controlled, and their location is limited only by the position of access doors to the unit. Because of these advantages, properly developed probes will yield more data in a shorter period of time than any other method.

The horizontal superheater probe consists of cylindrical test specimens screwed together and cooled with compressed air and temperature regulated by thermocouples embedded in the specimen walls. Specimens are machined in 2 in. ID tubular sections and are 1/4 in. thick and 1-1/4 in. long.

The details of a typical test cylinder and a diagram of the installed probe are shown. Note that the thermocouple well in the cylinder wall is drilled to within 0.040 in. of the outer metal surface, thus providing for accurate metal temperature measurements. (Fig. 3)

Figure 4 is a schematic diagram of the installed experimental apparatus. The apparatus consists essentially of three parts:

1. Probe to which the test specimens are attached.
2. A mechanism for regulating air flow to the probe for control of specimen temperature, and
3. A temperature recorder.

The probe is divided into two sections; one which is water cooled and serves as an arm to hold the other section which is air cooled. The sections are 2 in. diameter and may be any length desired within practical limits. Test specimens are attached as previously described to the air cooled section in three or more groups, each group containing up to six specimens. Temperatures are recorded. The temperatures of those specimens not containing thermocouples are estimated from the temperature versus location plot.

Regulation of the air flow to the probe controls the temperature of the specimens. The temperature gradient along the length of the probe permits the testing of a given alloy at several temperatures during a single test. Control of the air flow is accomplished by means of a manually operated valve plus two bypass solenoid valves which are activated by change in temperature of the centrally location thermocouple.

Where waterwall corrosion might be expected, the probe design and manner of installation are changed in an effort to closely simulate actual unit wall construction. This modification consists of mounting a length of tubing vertically in the plane of the furnace wall. Therefore, only half the sample surface is exposed to the furnace interior. Vertical probe construction and installation is shown in Fig. 5.

Low temperature corrosion potential due to sulfuric acid would be monitored by probes located in the back pass and operated at temperatures below the SO_3 dewpoint.

It is anticipated that probe tests would be carried out over at least one year with periodic inspections at appropriate intervals possibly as short as one month. The test firing schedule would influence this program. Test firing of the fuel could be halted if any of the test areas showed negative results.

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COMBUSTION ENGINEERING, INC.
KREISINGER DEVELOPMENT LABORATORY
FUELS SECTION WINDSOR, CONN.
ANALYSES REPORT

Horner and Shifrin
Mixed Refuse Sampling Test
Table 1

Sample	Test 1 (4-16-69)		Test 2 (4-29-69)		Test 3 (5-9-69)		Composite
Air Dry Loss	32.2		30.0		17.8		Meramec Coal
Wt. %	As Rec'd		As Rec'd		As Rec'd		
Moisture	34.4		32.6		20.9		
Ash	18.2		12.0		16.5		9.0
HHV, Btu/lb.	4550		4920		5810		10,990
Hydrogen	3.6		4.0		4.7		
Carbon	25.2		28.2		33.6		
Sulfur	0.34		0.35		0.33		3.5
Chloride (Cl)	0.11		0.16		0.19		

* Estimated on the basis of 82% Composite Coal and 18% Refuse

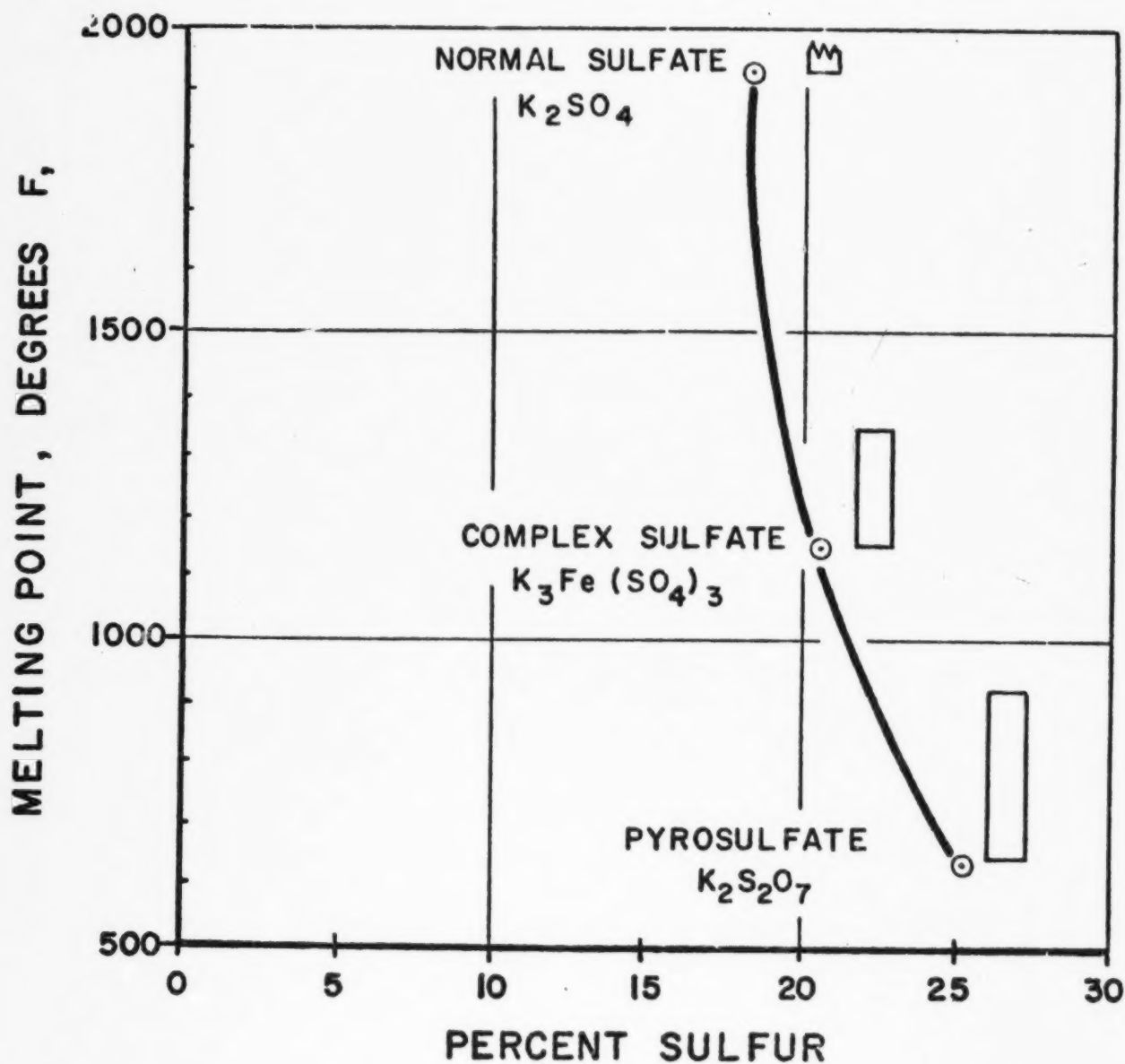
Table 2

Mixture	% Ash	Acid Soluble (ppm)		CaO + MgO % (as CaO)	Fe ₂ O ₃ %	Corrosion Index
		Na ₂ O	K ₂ O (as Na ₂ O)			
Test 1 4-15-69	10.7	910	1200	0.83	1.6	12.2
Test 2 4-29-69	9.5	890	1100	0.81	1.3	12.0
Test 3 5-9-69	10.3	890	1200	0.90	1.6	11.5
Coal Composite	9.0	800	1200	0.80	1.5	10.0

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TYPE OF POTASSIUM- SULFUR COMPOUND
VERSUS
MELTING POINT



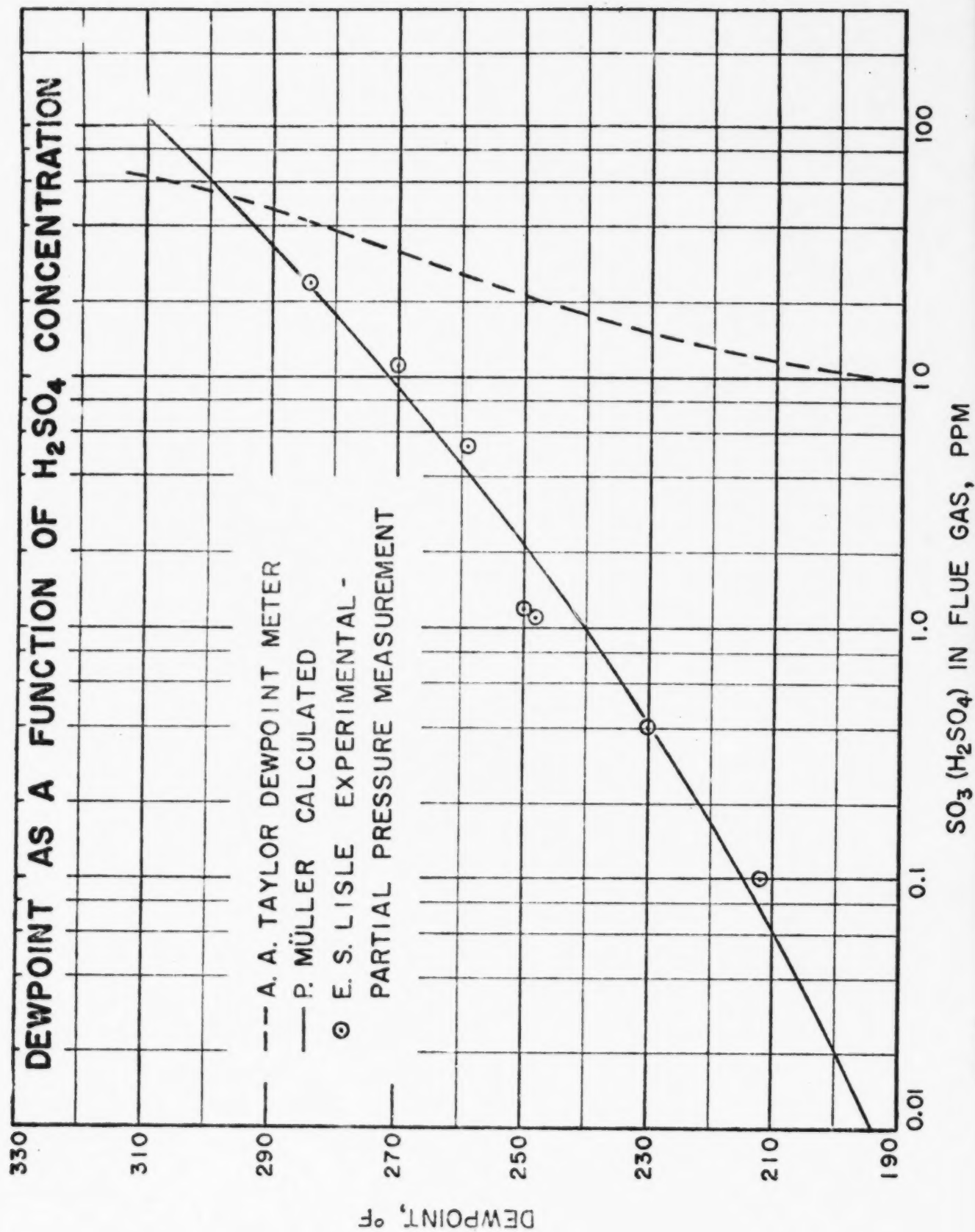
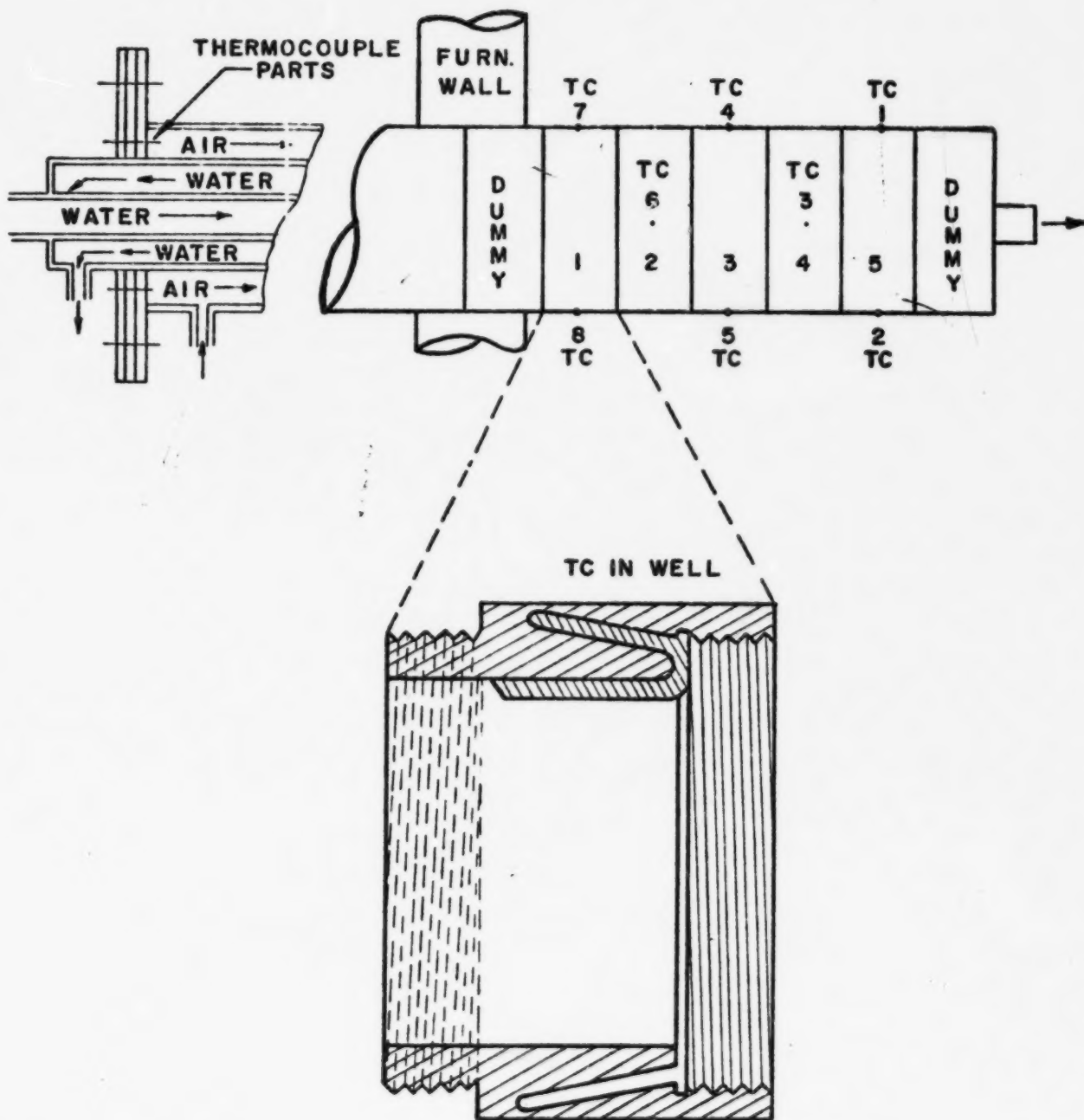


FIGURE 2



CYLINDRICAL TEST SPECIMEN

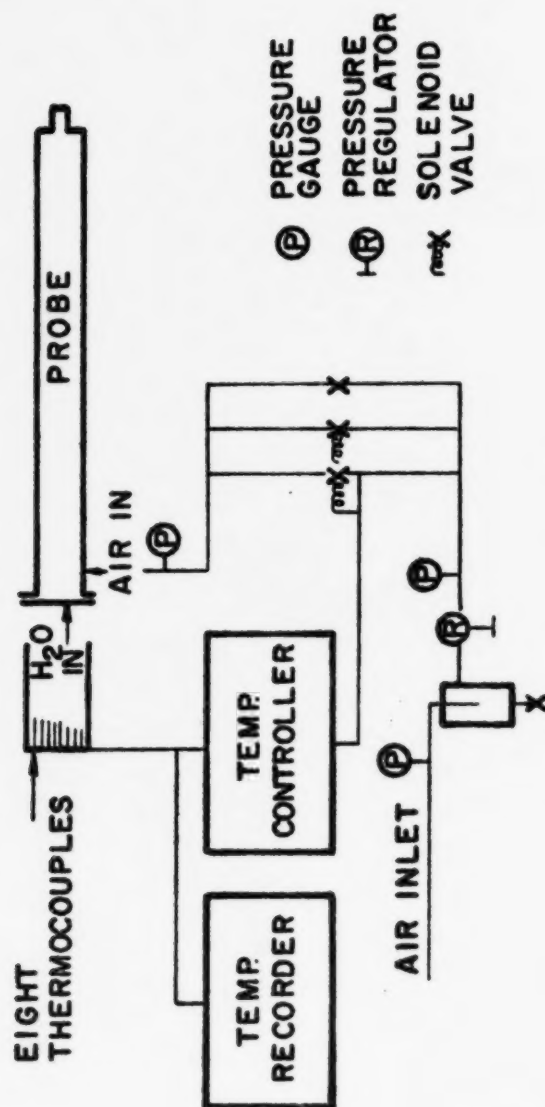
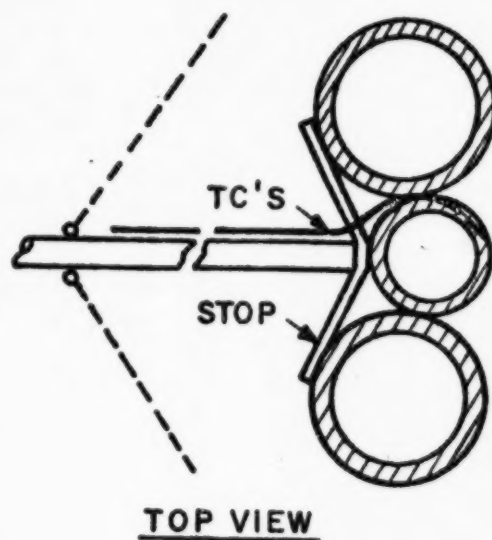
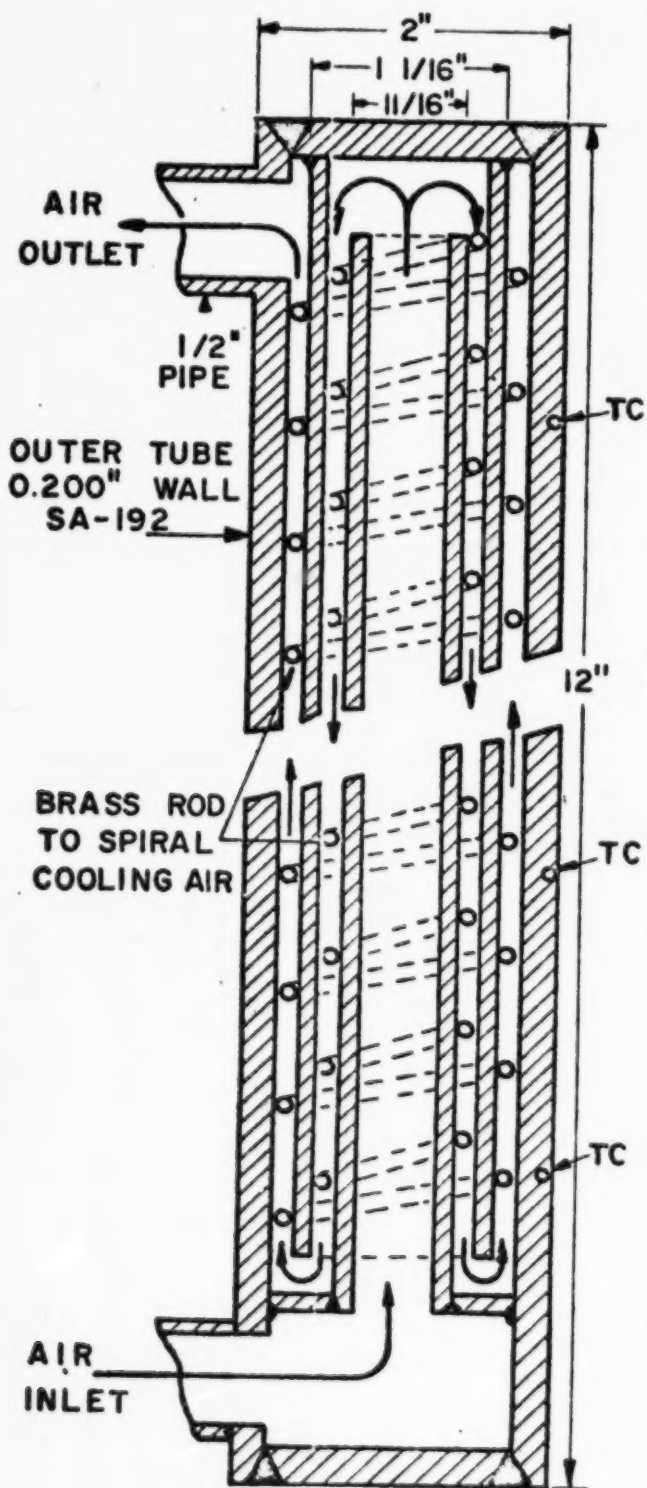
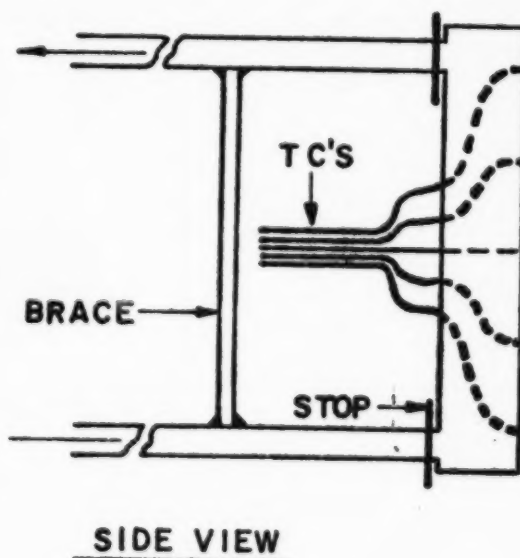


FIGURE 4



INSTALLATION DETAIL



10404

FIGURE 5